Compressed Air Magazine

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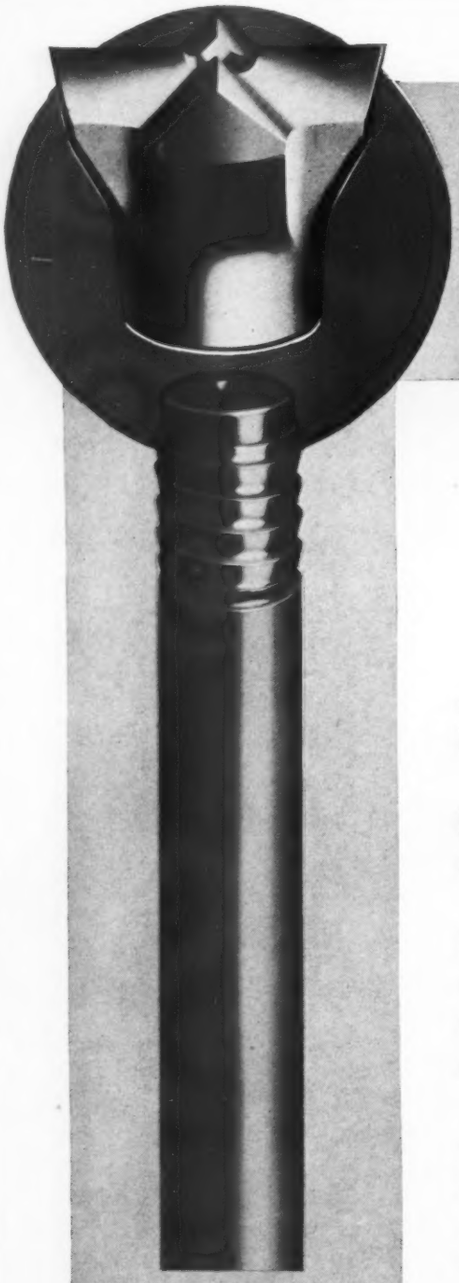
SAWING A HOT BILLET OF STEEL



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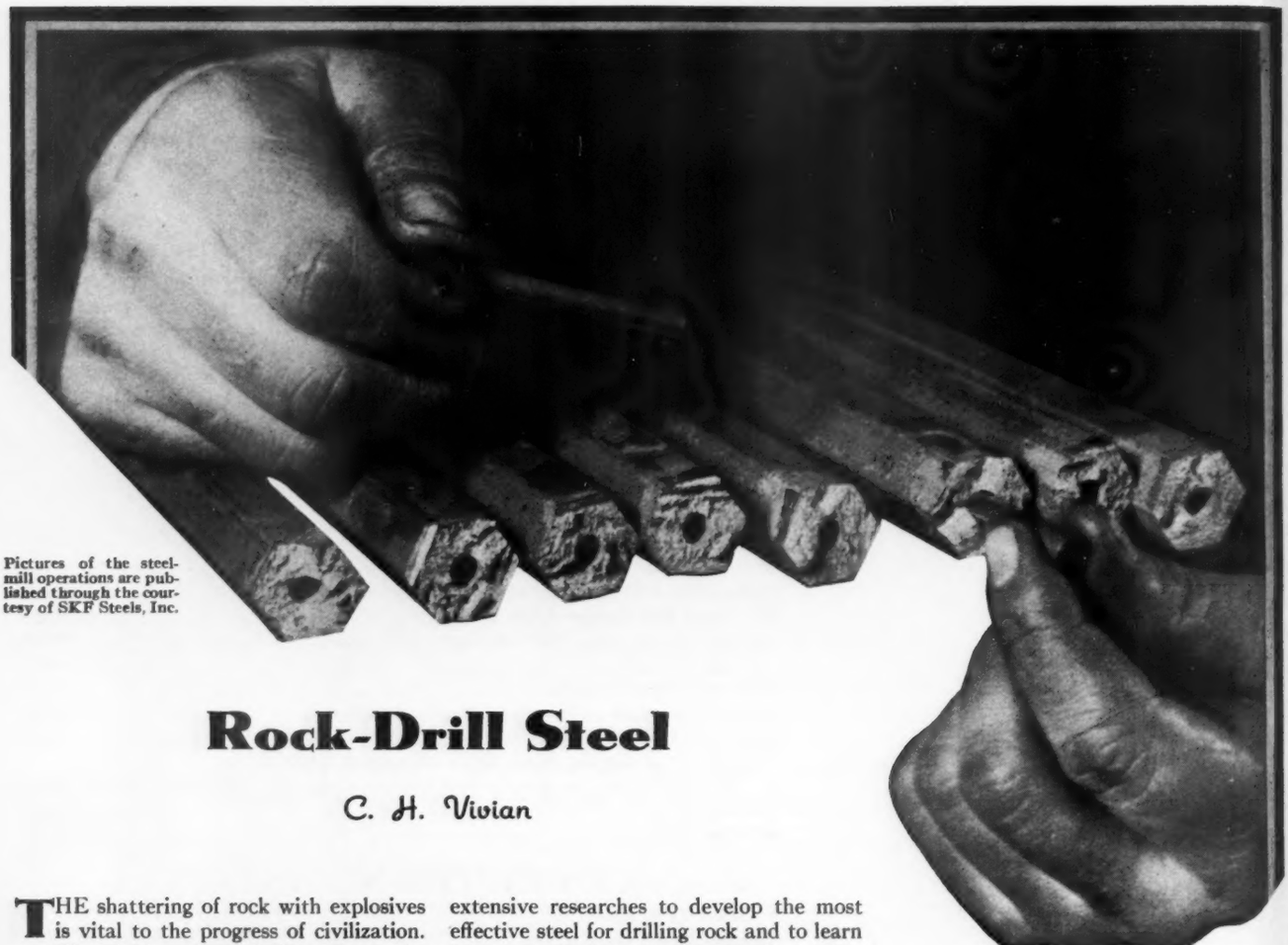


Pictures of the steel-mill operations are published through the courtesy of SKF Steels, Inc.

Rock-Drill Steel

C. H. Vivian

THE shattering of rock with explosives is vital to the progress of civilization.

The winning of metals from the earth; the quarrying of building stone and of materials for making cement, mortar, and plaster; the excavating of building sites; the construction of dams and of hydro-electric power plants; the establishment of grades for railroads and highways; the digging of canals and the boring of tunnels; the removal of obstructing ledges from harbors and ship channels—all these and countless other operations depend upon it. But, powerful though they are, dynamite and kindred substances cannot act effectively unless they are lodged within the materials it is intended they shall disrupt. To make it possible to place them where they will best accomplish their purpose is the driller's job.

The great bulk of the world's blasting is done within small-diameter holes which are made with compressed-air rock drills. Actually, of course, the drilling is done with a slender piece of steel bearing at one end a bit suitably shaped to cut into the material being penetrated. Although it could, obviously, not do its work if deprived of the driving force of the drill, the steel alone enters the hole and does the boring. Thus, the drill steel is the spearhead of the entire blasting process. Without dependable drill steel, the most powerful drill would be crippled. In view of these facts, it is easy to see why manufacturers of drills and makers of steel have coöperatively conducted extensive researches to develop the most effective steel for drilling rock and to learn how to make it so that it will best withstand the rigorous service to which it is put.

From these manifold investigations which, needless to say, are continuing all the while, the making of drill steel has grown into a specialized branch of the steel industry. World leaders in this respect are Sweden, Great Britain, the United States, and South Africa. In the latter country, where gold mining is the paramount industry and where copper mining is growing in importance, drill steel is of such significance that there is a steel mill devoted solely to its manufacture. Elsewhere drill steel is produced by concerns that also turn out other steel products.

The current world consumption of drill steel amounts annually to about 28,000 tons, which sells for somewhere around $6,000,000. South Africa uses approximately 7,000 tons, the United States 6,000 tons, and the remainder of the world 15,000 tons. It is of interest to observe that this steel, unlike that which enters into buildings, bridges, and machinery, is actually destroyed. Much of it is ground into powder by the abrasive action of the materials it drills, and there is, of course, a considerable loss from repeated sharpenings. An undetermined amount is broken in service, and some is reduced to lengths too short to be useful, and is discarded. As an indication of the drill-steel requirement of a large contracting job, it may be mentioned that the official Government report shows that Six Companies Inc. bought $149,000 worth during the construction of Boulder Dam.

CHECKING

Pieces of newly rolled hollow drill steel being checked for hole size. This is a part of the careful inspection that they must pass.

Prior to man's discovery of metals, the drilling of rock was an extremely arduous and tedious task. The first drills were simply rude chisels of hard stone such as flint, and these were struck by wooden clubs wielded by one man. They were used primarily for carving, and only occasionally for excavating. Bronze tools similar to chisels and crowbars next appeared. They were utilized in ancient mines such as the copper workings of Asia Minor and on the Island of Cyprus. No real progress was possible, however, until the advent of iron. The Romans probably were the first to use this metal extensively in mining. They employed solid chisels of iron; and even some case-hardened pieces—thus, actually steel—are sometimes accredited to them.

But even iron implements were of little effectiveness without explosives. They were not used to drill with, but to chip and gouge and pry pieces of rock from the face being worked. The traditional manner of

weakening the rock was by the thermal method. A roaring log fire was built against or upon the rock to expand it. Upon cooling, the rock contracted and some of it broke away. In addition cracks were created, and these openings permitted the insertion of bars and other tools. Usually, contraction was accentuated by dashing cold water against the heated area. Vinegar also seems to have been considerably employed for this quenching. A persistent myth that Hannibal resorted to fire and vinegar in building roads for his historic crossing of the Alps in 217 B.C. has caused no end of argument.

Fire setting, as this method of rock breaking was known, was used extensively in the European mines in the Middle Ages, and was described as standard practice by Georgius Agricola in his *de Re Metallica* published in 1556. In the translation of that volume, by Mr. and Mrs. Herbert Hoover, there is a footnote to the effect that fire setting was practiced in German and Norwegian mines to the end of the nineteenth century, or 270 years after the first application of explosives to mining. (Gunpowder was introduced in Schemnitz, Hungary, in 1627, but was unknown in England until 75 years later.)

The point of interest here is that the coming of explosives created a need for tools that would drill holes. Until mechanical drills were invented, such drilling was all done manually. In soft materials, rotating drills of the auger type sufficed. For drilling harder rock, either a churn drill or a hammer drill was ordinarily used. A churn drill is a long bar or pipe with a cutting bit at one or both ends and is alternately raised and dropped or repeatedly thrust against the rock face, according to the angle of the drilling. To increase its weight, a ball of iron is sometimes welded on near its midsection, in which case the tool is known as a ball drill. To facilitate handling by two or more men, one or more cross pieces are affixed to the drill. More familiar than this device is the hammer drill, which is still frequently used in prospecting and exploratory operations and sometimes in the work of production, particularly in small mines.

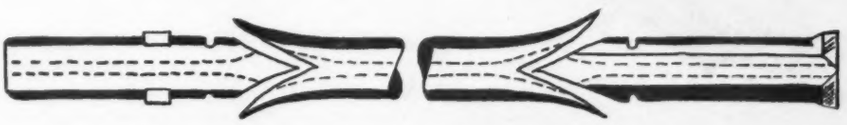
It seems hardly necessary to say that hammer drilling consists of striking the head of a chisel with a hammer. One man may hold the drilling tool with one hand and wield the hammer with the other, or, for deeper drilling, one man may hold it and one, two, or even three men may do the striking. Regardless of the number of workers, the chisel or drill steel is given about one-eighth of a turn between blows to insure effective cutting, to keep the hole round and straight, and to prevent rifling.

Even when hand drilling was the rule, some attention was given to the development of drill steel, and this fortunately was furthered by the development in the eighteenth century of cementation and, subsequently, of the crucible-steel process. However, it was not especially difficult to produce material that would stand up under a few blows a minute, and steelmakers did not give this branch of their industry serious study until the steam-powered piston drills fathered by Fowle, Burleigh, Ingersoll, Sergeant, Rand, and others came upon the scene during the middle and latter part of the nineteenth century. Even then they were confronted with no great problems, for those early drills did not impose severe service upon drill steel, as measured by present standards. They ran at low pressures, struck fewer blows per minute than modern air-powered machines, and operated with a solid-section drill steel of comparatively large diameter that was rigidly attached to the piston.

With the invention of the self-rotating hammer drill by J. George Leyner of Denver in 1897, it became apparent that there was real need for technologists to concentrate on drill steel. In the Leyner drill, the piston and drill steel no longer moved together as one reciprocating part. Instead, the steel was loosely held in a chuck and was struck a rapid succession of blows by the shuttling piston. This was a reversion to the principle of hand drilling. This basic feature of Leyner's design has been applied by all drill manufacturers since its introduction. The separation of the piston from the drill steel changed the nature of the stresses imposed upon the drilling element; but it was primarily another departure from previous practice that complicated the entire drill-steel problem. This was Leyner's adoption of a hollow drill steel for the purpose of passing air or water or both to the drilling face as a means of clearing away cuttings. This innovation had such recognized advantages that it quickly became standard, and remains so today.

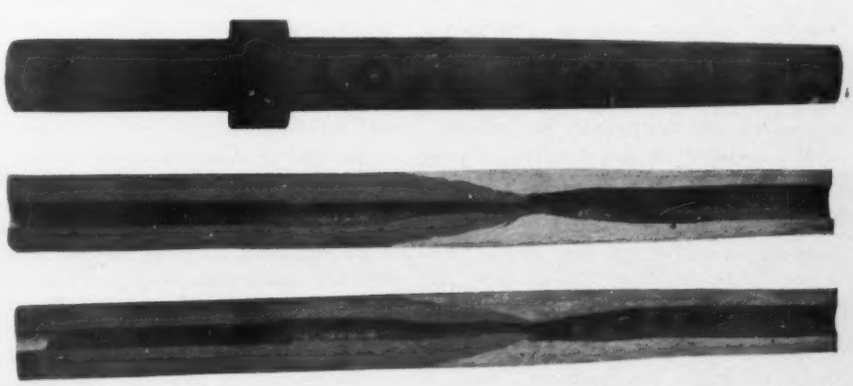
It can be readily realized that the hole greatly weakened the steel and considerably increased the likelihood of its failure in service. As a matter of fact, it set up difficulties that were then virtually unknown but that have since proved to be the foremost among all drill-steel manufacturing problems. These will be discussed more fully a little later: right now we are concerned with tracing the history of drill steel.

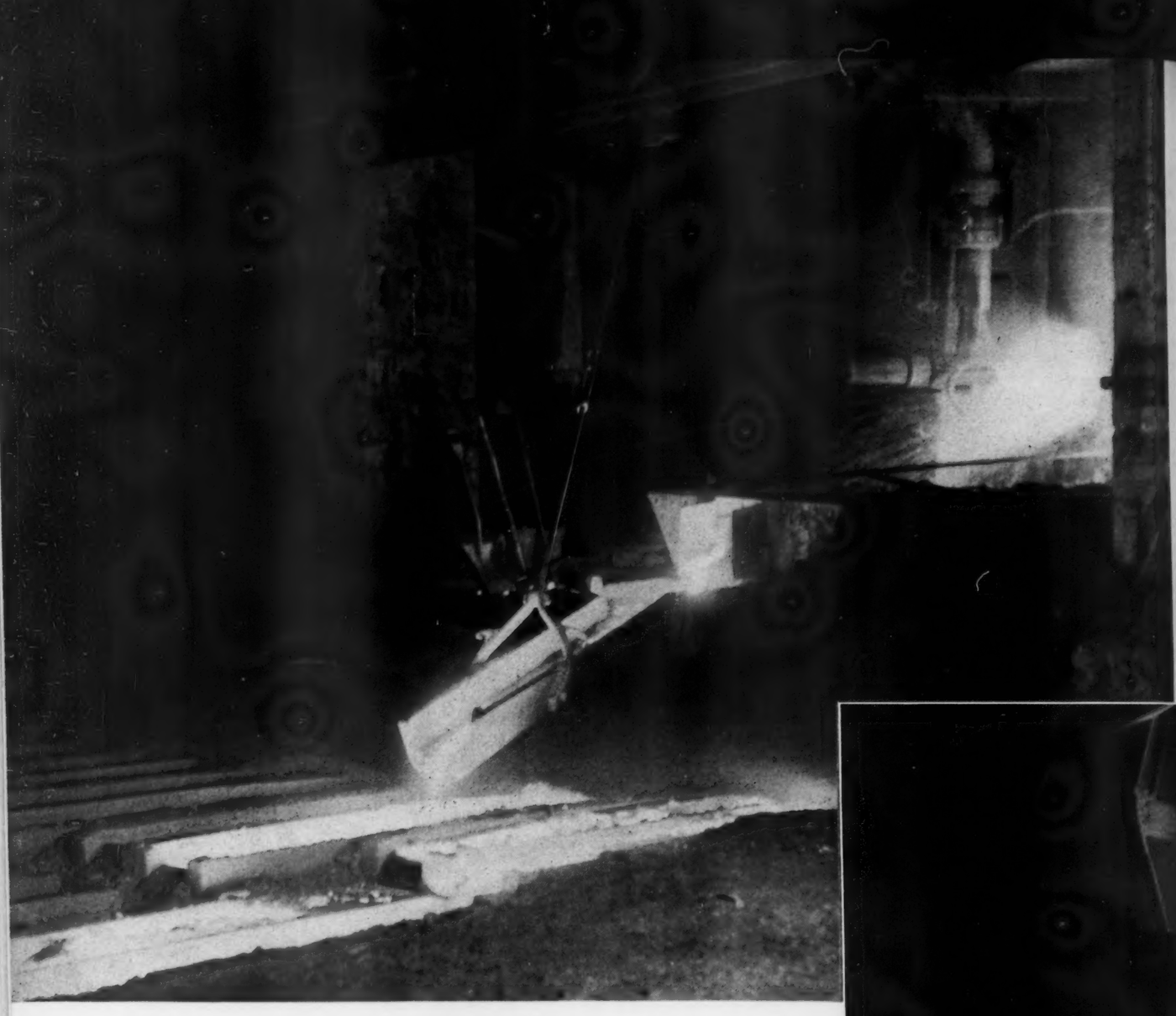
The resulting demand for hollow drill steel found no such article on the market and no steel mill capable of turning it out.



EARLY HOLLOW STEEL

The pictures below show the shank end of a piece of steel, 13¾ inches long, which was picked up recently in an old Colorado mining camp. It is readily identifiable as a product of the J. George Leyner Company of Denver during the early days of hammer-drill production when steel mills had not yet learned how to roll hollow steel. Shank and bit ends were machined from solid stock, pierced by drilling, and then welded to a center section of staybolt iron, which was used because it was hollow. The sketch above illustrates these parts and shows how they were prepared for assembly. As the dotted lines indicate, the hole was enlarged with a punch at the ends that were to be joined so as to prevent subsequent closure. The center section was "fishtailed" at the ends, and to make a temporary union the points were hammered down cold into notches cut in the shank and bit sections. The joints were then spread with borax and the piece placed in a furnace for welding. This old specimen was cut longitudinally and etched with acid to bring out the union between the shank at the left and the center section at the right. It can be seen that the hole in the shank was drilled from the two ends. Measurements show that the hole was contracted to as little as ⅛ inch by the welding, and it will be noticed that its width varies greatly throughout its length. At the right end of the upper picture a crack gives evidence that the center section was originally formed by butt-welding. Analysis and metallographic examination of the specimen reveal that both sections are low-carbon steel—the part in the center being similar to stock now used for making barbed wire. Phosphorus and sulphur content are much higher than would be permissible in rock-drill steel of today. Manganese, silicon, chromium, and vanadium are also present. The steel in both sections was evidently made by the Bessemer process.





In that exigency, the drill manufacturers decided to make it themselves. This called for considerable ingenuity, and the product was of necessity a compromise dictated by the materials and equipment available. The so-called steels produced by the Leyner Company were mostly iron, the entire middle portion being a piece of staybolt iron that was used because it had a hole through it. Shorter pieces of steel, which had been bored previously and been properly formed into a bit and shank, respectively, were then welded on to either end. The bit and shank were kept more or less standard in length, while the iron section was varied so as to provide the different lengths of steel required to make a complete drilling set. This was an expensive procedure, and the product was not thoroughly satisfactory, but it sufficed for the time being.

As nearly as can be learned, this improvised hollow drill steel was first used sometime between 1894 and 1898 in the Newhouse Tunnel at Idaho Springs, Colo. As the beginning of this period antedates Leyner's announcement of his hammer drill to the trade, he was then probably trying it out in the field. The Newhouse Tunnel, a 4-mile bore that was driven to provide a haulageway for various mines on the divide between Idaho Springs and Central City, is still used to some extent and is now known as the Argo Tunnel. It was extended from time to time, and its construction stretched over a span of approximately fifteen years. Much of it was driven with Leyner's built-up steels, which also accounted for a vast amount of mining work done during that same general time.

It should be understood that the adoption of the hammer drill was gradual and that large numbers of piston-type drills continued to be used, thereby maintaining the demand for solid drill steel which the established steel companies supplied. Meanwhile those manufacturers of drills who had turned, in part at least, to the hammer-type machine were continually seeking a better method of making hollow steels.

After the composite section originated by Leyner, the next step seems to have been taken by Ingersoll-Rand Company at its Phillipsburg, N. J., factory around 1908. A number of machines such as were used to bore gun barrels were installed, and they served to produce hollow steels which gave good service. The boring tool was stationary, and the bars being pierced were revolved while in a vertical position. The

MAKING THE STEEL

Drill steel is high-grade tool steel, and great care must be exercised in making it to give it the desired characteristics and to eliminate harmful amounts of impurities. Phosphorus and sulphur are No. 1 Enemies of drill steel. They are contained in most iron ores and in blast-furnace coke. Sweden sprang to the fore in drill-steel making because of the high purity of its ore and the fact that charcoal, instead of coke, is principally used to reduce it. Where objectionable amounts of phosphorus and sulphur enter the steel, the steelmaker must get rid of them by expensive refining methods. It is generally recognized that better steel can be made by producing it a little at a time, thereby permitting close control of the processes. Illustrated here is a sequence of operations in the SKF mill at Hofors, Sweden. At the upper left, pig iron is being tapped from a blast furnace. From the pig iron and selected scrap is made steel in small acid, open-hearth furnaces (capacity 16 tons). The white-hot steel is withdrawn into a ladle, (above), which moves above a line of ingot molds, hovering over each one just long enough to fill it (left). In accordance with generally accepted practice, ingot molds are small and tapering, and each receives its charge of metal with the big end upward, thereby lessening trouble with segregation and "pipe" formation.

boring limit was about 4 feet; and even by reversing a bar after one end had been pierced it was not possible to turn out steels longer than 8 feet. The holes were not always centrally located, and when bored from the two ends they did not always coincide upon meeting. Aside from the inability to produce these steels in long sections, there was the further drawback that they were very expensive to manufacture, and this mitigated against the use of the hammer-type of machine drill. Drill makers were therefore glad to relinquish the task of providing steels to the established steel companies as soon as the latter had developed a method of rolling hollow sections.

Steelmakers both here and abroad at first followed the practice just described—that is, they produced a solid steel bar, cut it into the lengths required in the field, and then drilled a hole through each. Then another branch of the industry began to make a seamless steel tube by rolling it over a supporting mandrel placed centrally between rolls. This method was applied to the manufacture of drill steel; but it proved impractical when the mandrel was reduced to below ¾ inch in size, for drill steel with holes of ¼ to ⅜ inch are most often used. To reduce the hole size to meet require-

ments, the final few passes of the steel through the rolls were made without the mandrel inside. Despite its limitations, the mandrel method resulted in a better product than had hitherto been available.

Reverting now to the primary difficulty with which steelmakers were confronted upon the introduction of hollow drill steel, it was found that steel failed not alone because of the reduction in section but also because of minute pits and depressions on the inner surface which eventually developed into weak points that led to breakage. Repeated investigations have proved that unevenness is fatal to the life of drill steel. It is a comparatively easy matter to roll the outside surfaces smooth, but the problem from the start has been to do this on the inside.

The practice of rolling partly over a mandrel and partly unsupported resulted in too many interior folds and crevices to give the steel the desired serviceability. The hole was fairly concentric, but the incipient weakness was there. Moreover, drills of greater power were continually being developed, and the demands on drill steel were consequently increasing. Some better method of production had to be found, and continuing research led to the sand-core process.

This consisted of the following operations: Ingots that were normally poured from furnaces into molds having diameters of 10 to 24 inches were heated and reduced in rolling mills to billets about 4 inches square. These billets were then cut into lengths of some 3 to 8 feet and pierced with a central hole from 1¼ to 1½ inches in diameter. This hole was packed tightly with sand, after which both ends were plugged. Next, the billets were reheated as if solid, and rolled down to finished size, say 1-inch hexagon. During the rolling the hole was reduced in diameter to around ¼ inch. The plugs were then removed and the sand blown out with compressed air. The re-

READY FOR ROLLING

Above is an end view of a pile of billets, each of which has been pickled, had its surface defects removed by chipping or grinding, and been cut into rolling length, pierced through the center, and filled with a core of austenitic steel. The usual billet section is about 4 inches, in which case the diameter of the hole is around 1¼ inches. Rolling will reduce the billet and core proportionately, thus producing a hole of standard diameter for the size of finished steel being made.

ROLLING HOLLOW DRILL STEEL

Billets and their austenitic cores are heated in a furnace which is carefully controlled as regards temperature and other conditions. They are then reduced to the desired section by successive passes through rolls providing progressively smaller openings.

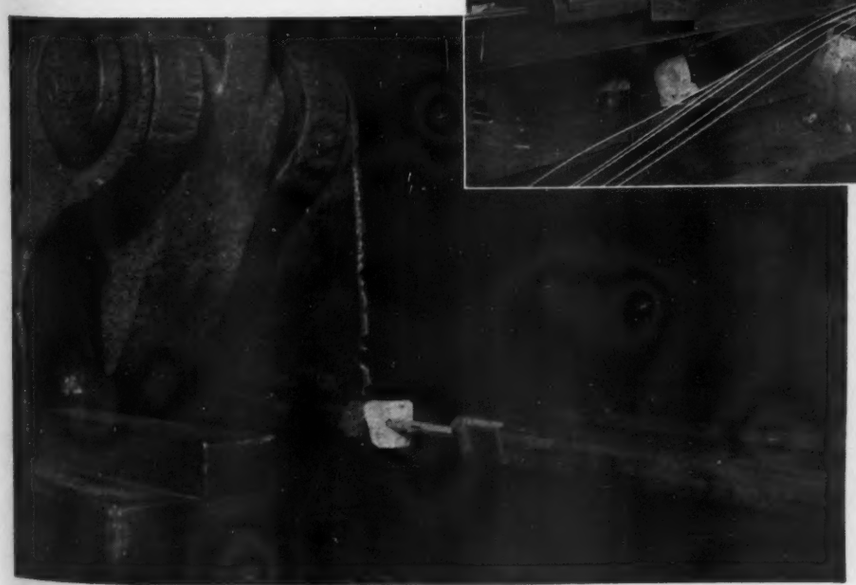
sultant hole was the smoothest and straightest that had yet been produced, but in the walls were small indentations and irregularities, impressions of the grains of sand. In an effort to eliminate these imperfections, finer sand was employed; but they persisted, although in lesser degree.

Again the steelmakers attacked the problem, and the outcome of their investigations was the process of rolling the pierced billet over a metal core. Not all metals are suitable for this purpose, however, and it was not until the invention of the austenitic process in Great Britain by Harry Brearley in 1926 that a satisfactory material was found. As far back as 1913 the use of a lead core had been tried in Sweden, and at about the same time Walter E. Ludlum experimented with iron cores at Pompton, N. J., but neither of these pioneer efforts proved fully successful.

Austenitic steel, as introduced by Brearley, overcame the chief difficulty—that of removing the core from the finished drill steel. This material, which contains chromium and nickel, has elasticity—with its attendant reduction in cross section when elongated—and possesses the added virtue of not snapping back to its original length, as does a rubber band, when the stretching force is released. Accordingly, it can be withdrawn from the rolled product with ease. It is inserted in the hole in the billet prior to rolling, and is allowed to protrude at both ends. Following the rolling operation, it is grasped by a clamping device at each end and pulled. This reduces its diameter so that it can be readily removed by hand. The hole thus formed is almost as smooth and uniform as a gun barrel. The inside walls are protected by the core during the necessary reheatings and thus safeguarded from decarburization. A little chromium is even diffused from the austenitic steel into the drill steel at high temperature, thereby materially improving its resistance to corrosion.

The rights to the Brearley patented method were secured in 1927 by the SKF interests, internationally known as manufacturers of ball bearings, and have since been used in the production of drill steel of first rank at their Hofors mill in Sweden, where advantage is taken of the unusually pure iron ore and of the long experience in steel making. The success of the Brearley process naturally invited followers, and while most manufacturers of drill steel are secretive about the details of their methods it is known that many of them utilize some form of metal core.

We may now inquire a little more closely into the character of such drill steel and point out definite reasons why it is difficult to make a truly satisfactory product. It may be from ⅞ inch to 1½ inches in diameter (up to 2 inches in the solid type), and anywhere up to 40 feet long, depending upon the character of the drilling work. In a modern rock drill, it is struck from 1,600 to 2,200 blows per minute, and behind each blow is the full force of 80 to 105 pounds of



EXTRACTING THE CORE

Following the rolling, the bars and their contained cores are allowed to cool and are then placed in a special fixture for loosening the core. The ends of each bar are broken, but the core, because of its special properties, does not break. After that the ends are clamped and the core is subjected to stretching. This elongates it and reduces its diameter throughout its length, thereby freeing it from the walls of the drill steel. The core is next cut at one end, after which it can be withdrawn by hand. The stretching operation is shown above and at the left, the latter being a close view of one of the clamps and illustrates how the tension is applied.

EVOLUTION OF THE HOLE

The hole is one of the most important parts of hollow drill steel and has been the object of much research. It should be round, be in the center of the steel, and be of uniform diameter throughout its length. The paramount requirement, however, is a smooth wall surface. Failures of rock-drill steel are of two general kinds: sudden and progressive, and most of them come under the second heading. Metallurgists call them fatigue failures. They start from pits and other irregularities in the surface. It is comparatively easy to roll drill steel so that the exterior surface will be even, but it took many years to find a way to do the same thing for the inner or hole surface. Here are shown three steps in the development of the super-smooth hole: Left, a steel produced by sand-core rolling; center, a specimen rolled by the mandrel method; right, one formed by the metal-core process now in use.

air pressure. With each blow, the bit end strikes against the rock face, sending much of the force back along the steel in the form of vibrations, and these vibrations increase in intensity as the bit becomes duller or as the rock becomes harder. Add to this the torsional strain imposed by the rotation of the steel, and it is evident that even normal service imposes severe punishment upon it. But service is often abnormal.

Unskilled workmen, below-par drilling machines, and a hundred other factors at times add unnecessary abuse. Nor does the steel retain its original hardness, for it undergoes periodic redressing. Variations in the heat and technique of tempering are bound to occur, particularly where experienced help and modern equipment are not available. A final circumstance that shortens the life of drill steel is rough handling. Being what it is, it is thrown around with disregard, is cold-straightened when it becomes bent, and often lies in wet places, acquiring nicks, strains, and rust which hasten the time when it will fail.

Simultaneously with the improvements in the mechanical surface conditions of the hole, progress has been made in drill-steel metallurgy. The very nature of the requirements of drill steel have complicated this problem from the outset and have forced the steel experts to make concessions. At one end of the steel is the bit, which should preferably be as hard as a diamond to assure maximum penetration and wear resistance. But at the other end—the shank end—the steel should be as tough as rubber to withstand the tremendous shock and vibration of the incessant pounding it receives. Manifestly, both these demands cannot be fully met in one piece of steel, and a compromise has to be made.

The greater part of all hollow drill steel is now made of straight carbon steel. It is the amount of carbon that principally determines the properties of such steel. Various localities and various individuals have always had conflicting ideas as to the carbon content most suitable for drilling their kind of rock and meeting other specific conditions, but in recent years the trend has been towards uniformity. Experience has taught that in the majority of cases a compromise carbon content of 0.70 to 0.80 per cent is most effective, and such steel is usually furnished unless one of a different analysis is specified.

Alloy steels have been used for drill steel to only a limited extent, the primary reason being that they require more particular forging and hardening treatment than do straight carbon steels. Suitable equipment for this treatment is not available at the average drilling site. Investigations of the applicability of alloy steels are proceeding, however, and it is possible that they may be employed to a greater extent some time in the future. One indicated advantage of alloy steels is their greater tensile strength. This permits the use of lighter sections and smaller bits, with a consequent increase in drilling speed. A smaller drill hole results, of course, and consideration must be given to this fact in determining whether the desired explosive effect can be obtained.

Some physical changes in drill steel also took place in the course of the developments that have been recounted. Before hollow steel came into being, the bars were usually of round, cruciform, or octagon section. Primarily to make it easier to grip the shank end for rotating it, hexagon steel was adopted when the first "Jackhamers" appeared. Present practice is to utilize hexagon steel for "Jackhamers" and round for all other types of hammer drills. The relatively few piston drills that are still in service, principally for submarine work, use solid steels of round, octagon, quarter-octagon, or cruciform section.

Many changes have also been made in the types of bits employed. As chisel bits had been used for hand drilling, it was natural that they should be the first to be tried for machine drilling. New types soon appeared in profusion, however, and for many years there was much controversy over the relative merits of each. Gradually there was a movement towards standardization, with the result that the 4-point bit now greatly predominates. The chisel bit, or modifications of it such as the Carr bit, seem to be next in popularity, with the 6-point bit third. Other types have only scattered application.

Although an analysis of any operation involving rock removal will conclusively prove that money can be saved by using the best drill steel obtainable, this fact is not always obvious, and many companies and individuals do not realize that they might get better results by paying closer attention to this comparatively minor piece of equipment. Both drilling performance and long life are requisites of good steel. When a steel breaks in a hole in a mine it not only necessitates drilling a new hole but it may also mean the loss of a blasting round for the shift. Thus the quality of the steel may very considerably affect the over-all efficiency of a mine, quarry, or contracting operation.

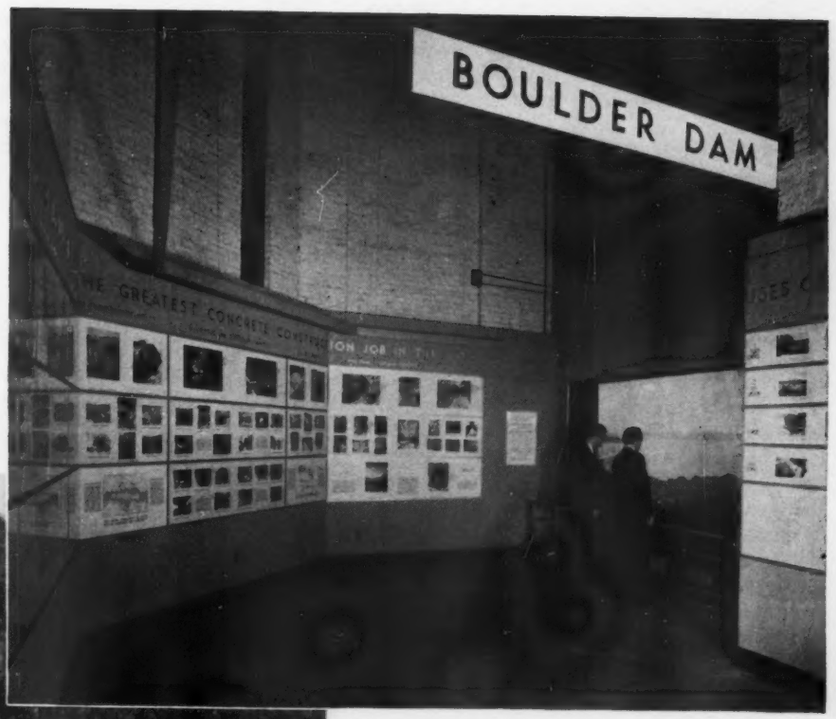
To obtain reliable comparative data on different brands of drill steel, not only first costs but also operating costs should be considered. To facilitate the compiling of operating costs, steels should be marked for identification so that pieces that have been in use for some time can be distinguished from new lots of the same brand.

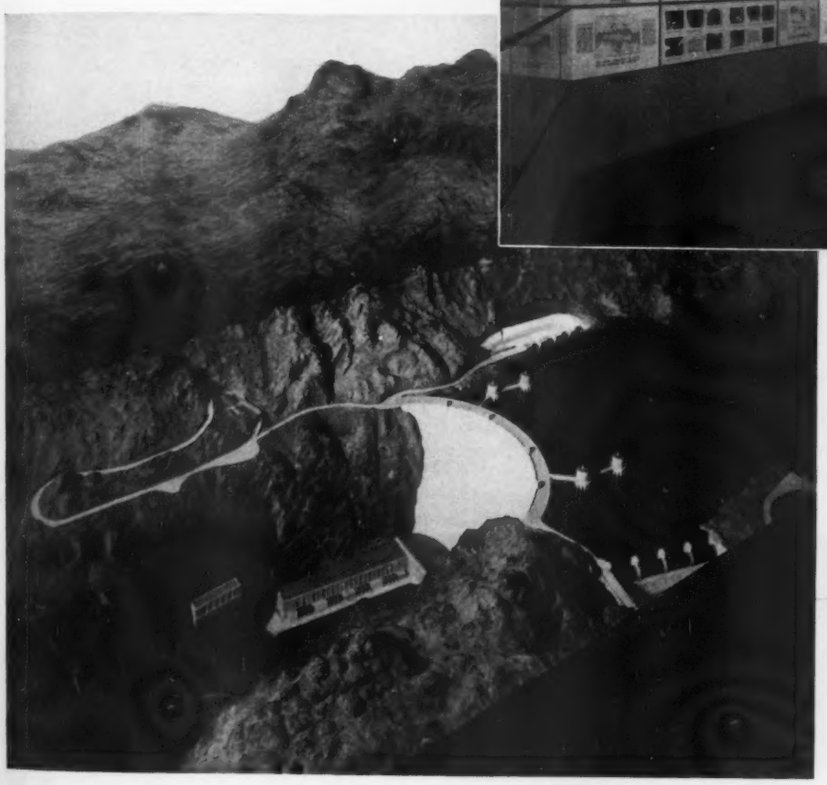
Where hard rock is being drilled in a mine, a piece of steel may be in service only two or three minutes before the bit becomes dull. It is then sent to the shop for reconditioning and may not be returned for two or three days. It may be used no more than twice a week, and its total service for a month may amount to no more than 20 or 30 minutes. Unless a careful record of actual drilling time is kept, such a steel may seem to be giving good service when it shows no breakage for six months, while actually its performance is poor.

It may be mentioned in conclusion that the introduction of detachable bits has imposed more rigorous requirements on the steelmaker than ever before. A drill rod may be used as many as 30 times in a shift, in which case its service for one day equals that of a fixed-bit steel for three or four months. This intensified application proves the worth of the steel that much quicker; but in either case the actual amount of drilling before failure is the only correct figure upon which to base the comparative merits of competitive brands of steel.

Boulder Dam Officially Completed

Copeland Lake





THE DAM IN MINIATURE

To give visitors to the Century of Progress at Chicago a conception of Boulder Dam, the Bureau of Reclamation prepared a model in the form of a diorama. It is arranged so that a 4-minute cycle of operations will show how the water will be handled during normal and flood periods. This model, built on a scale of 1 inch to 30 feet, has since been made the central feature of a Boulder Dam exhibit at the Museum of Science and Industry in Chicago. Supplementing it are groups of photographs, maps, and colored drawings illustrating various phases of the project and of the construction work at the dam site.

BOULDER DAM was officially completed on March 1, when the U. S. Bureau of Reclamation accepted it from the builders, Six Companies Inc. Formal acceptance was by Secretary Harold L. Ickes, of the Department of the Interior, in Washington. At the dam site itself there were no formalities. Frank T. Crowe, general superintendent for the contractors, and Ralph Lowry, project engineer for the Bureau of Reclamation, merely went out together to look at the huge structure, voiced the mutual opinion that it was a pretty good-looking piece of work and ought to stand up for a long time, and let it go at that. When they turned away, the Government had become the owner of a 7,000,000-ton block of concrete that had cost $54,700,000 (including the power house), and Mr. Crowe had been divested of the responsibilities of directing the largest construction job ever undertaken.

The building of Boulder Dam consumed exactly eleven days less than five years. It was finished 728 days ahead of the completion date, April 28, 1938, specified in the contract entered into on March 11, 1931. The contract price was $48,890,995.50, which, it is interesting to recall, was just $24,741.50 more than the cost estimated by the Bureau of Reclamation. Actually, however, Six Companies Inc., received $54,700,000 for its work, of which $51,950,000 was paid in cash and $2,750,000 in the form of electric power and rental of ground in Boulder City for buildings used by the contractors. The payment of $5,809,004.50 over and above the contract figure represented compensation for extra services entailed by reason of changes made in the plans and design after the specifications had been drawn. One such change added $2,000,000 to the cost of the power house. Another major alteration increased the diameter of the penstock-header tunnels from 30 feet to a size sufficient to permit steel pipe of 30-foot diameter to be placed in them. This involved more excavating, which came to $1,000,000.

The only important contract item not yet completed is the installation of a concrete plug in one of the four diversion tunnels. This was delayed by the Government because of the necessity of utilizing that tunnel to by-pass water for downstream irrigation purposes until the power house is ready for operation. The plug will be placed by force account when conditions are favorable. The Bureau of Reclamation has also taken over some of the contractors' plant and equipment and will use it without charge until October 1 in setting up power-house machinery and in putting certain finishing touches on the structures.

Final figures show that Six Companies Inc. poured 4,364,903 cubic yards of concrete, for which they received $19,305,198. Of the total, 3,240,871 cubic yards was placed in the dam proper. These quantities are in sharp contrast to the 3,690,000 cubic yards poured in the case of almost 100 other

dams constructed by the Bureau of Reclamation up to 1933. All excavating incidental to the contract amounted to 5,965,972 cubic yards, a substantial proportion of it being rock. This earned Six Companies Inc. $27,433,627. For driving the four 50-foot diversion tunnels the contractors were paid $12,914,874, this being the largest single item of the construction program. The Babcock & Wilcox Company has yet to finish its $11,000,000 contract for the fabrication of steel pipe and its installation within the penstock tunnels.

The first of the four systems that will carry water to the turbines was successfully tested on December 26 under a hydraulic head 50 per cent greater than it will have to withstand under operating conditions. This test was made by closing both ends of the penstock header as well as the lower ends of the take-offs to the power house, and by pumping into the pipe the 9,000,000 gallons of water required to fill it. The pumping took three days. The additional head was obtained by filling a standpipe with water to an elevation of 648 feet above the center line of the penstock header and 831 feet above the outlets to the power house. The pressure thus applied was approximately 280 pounds per square inch in the 30-foot header pipe and 360 pounds per square inch in the 13-foot take-offs to the turbines.

Although it was known that 9,000,000 gallons of water would fill the penstock system, it was found necessary to add a further 25,000 gallons to compensate for losses in volume resulting from the compression of air entrained in the water and from expansion of the pipe under pressure. It is expected that the first 82,500-kva. generator will go into service in May of this year. It will serve the City of Los Angeles. Seven of these units will be installed this year. Eventually the power house will contain fifteen of that size and two 40,000-kva. generators.

Boulder Dam went to work thirteen months before it was completed. Immediately upon the closing of the gates to the diversion tunnels on February 1, 1935, the flood menace was removed from Imperial Valley and that area was insured an ample year-round supply of irrigating water. During the spring of 1935 the river flow reached 105,000 second-feet, which would certainly have caused damage in the lower Colorado Valley had it not been abruptly halted by the dam. Some of the water stored during this flood stage was released from the reservoir later on in the summer and diverted by the canal system to the Imperial Valley for irrigation. The result was bumper crops, as contrasted with losses estimated at $10,000,000 in 1934 because of an inadequate water supply.

The reservoir that is being formed by Boulder Dam has very appropriately been named Lake Mead, this designation having been officially made by the Board of Geographic Names in recognition of the part played in its creation by the late Dr. Elwood Mead as Commissioner of the Bureau of Reclamation.

Photo by E. B. Edwards, Las Vegas, Nev.

A LANDMARK DISAPPEARS

The picture shows the tops of the walls of the warehouse at old Fort Callville about to be covered by the rising waters of Lake Mead as it appeared on April 14, 1935. The Mormons, intending to use the Colorado River as a commercial route to California, established the settlement in 1864, naming it for Anson Call, leader of the party that built it. The site was 7 miles above Boulder Dam, at the head of navigation. A boat landing, large warehouse, corrals, and a number of dwellings were constructed. Great hopes were held for the future of the route, and Salt Lake papers advertised regular service to and from New York and Europe via the Colorado River, Gulf of California, and Isthmus of Panama. A few trips were made, the boats being eased downstream or pulled upstream through the rapids of Black Canyon by ropes attached to ring bolts moored in the cliffs or large bowlders. The venture was given up in 1866 and the fort was deserted. The last recorded use of it was in 1868, when three fleeing horse thieves broke down the heavy doors of the warehouse, converted them into a raft, and made their escape down the river.

Lake Mead is already more than 80 miles long. It will ultimately reach 115 miles up the Colorado River, will be as much as 40 miles wide, and will cover 229 square miles. It will contain 30,500,000 acre-feet of water and will be the largest man-made body of water in the world. It will be under the joint supervision of the Bureau of Reclamation and the National Park Service. It is expected to become a mecca for tourists and sportsmen. Already 200 boats, including a 32-foot cruiser, are operating on it. The location of such a recreational spot in the middle of a desert insures its popularity; and Doctor Mead estimated that it, together with the dam, would attract 500,000 sight-seers and vacationists annually.

As soon as the lake began to attain depth the water lost its traditional murkiness. Observers report that it is a dark emerald green in the canyons above the dam and a deep blue in the more open country. For 25 miles below the dam the water that is released flows sparkling clear. As this water will be withdrawn from the lower levels it will always be cool, and it is planned to stock the stretch below the dam with trout. Already bass have been placed in the lake, and more will be added, together with crappie, bream, and perhaps other fishes. To replenish the supply regularly, a hatchery will be built nearby—a $60,000 appropriation for that purpose having been made.

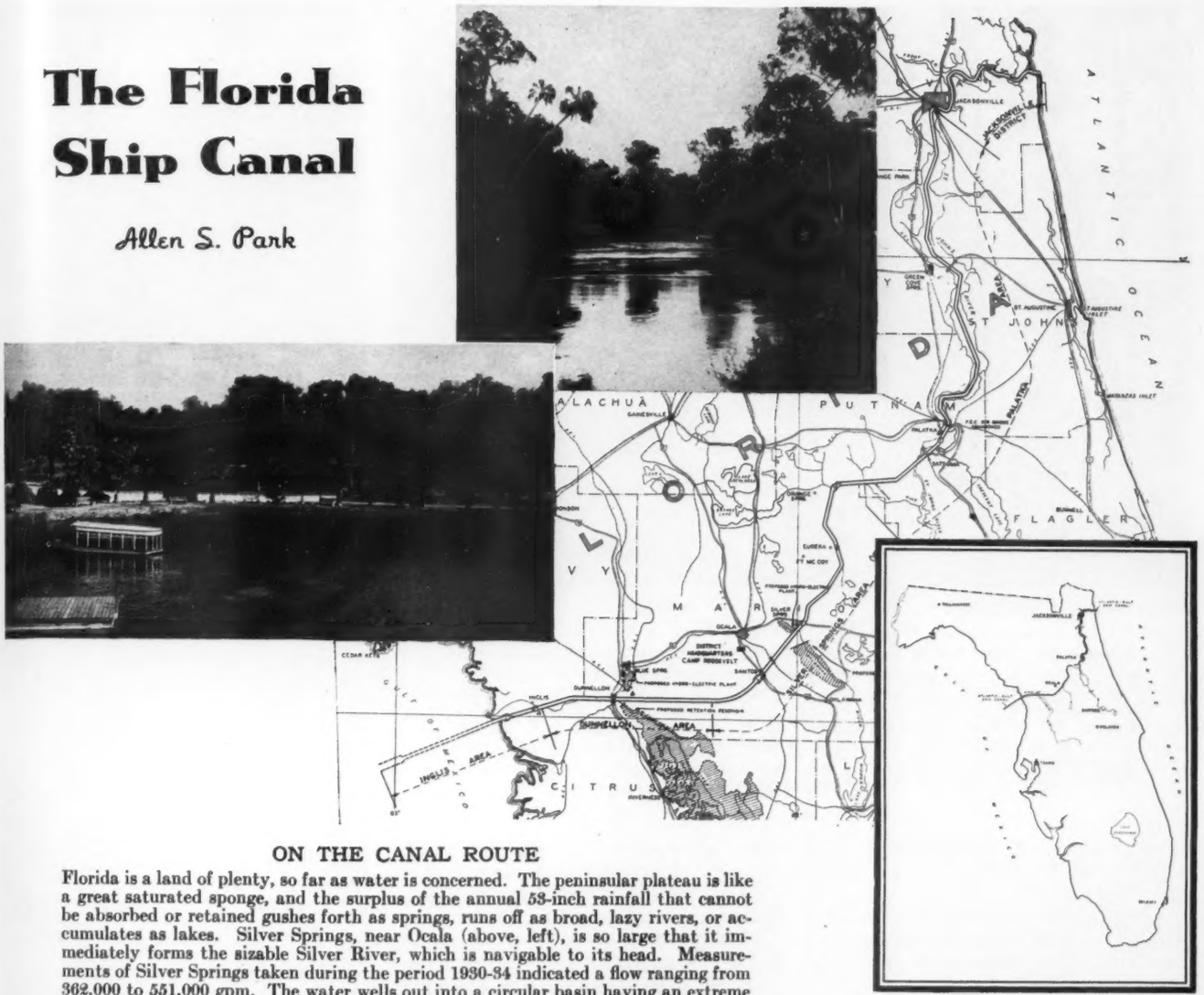
The lake has also opened up a scenic wonderland, having provided a means of access to sections of the canyon through which less than half a dozen boats had ever passed before the dam was constructed. An exploratory trip by a Bureau of Reclamation party disclosed many beautiful sights, including a 185-foot waterfall which was not known to exist. As Lake Mead grows, it will inundate the towns of St. Thomas and Kaolin, Nev., in the Moapa Valley, the old Mormon settlement of Fort Callville, and the Pueblo Grande de Nevada, the "Lost City", which archaeologists say was inhabited 1,200 years ago.

One of the interesting scientific benefits of Lake Mead will be the opportunity that it will afford for studying the effect of a great weight superimposed upon the earth's crust. It has been computed that the impounded water will weigh 41,500,000,000 tons, which is far greater than any single mass previously set down on the surface through the work of man. It is the opinion that this will cause a gradual and, eventually, an appreciable settlement of the area.

To permit geophysicists to measure and to investigate the movement, bench marks will be carefully established by engineers of the Coast and Geodetic Survey in the area that is expected to subside. After the reservoir is filled, new levels will be run and the results compared. These studies, it is believed, will lead to a better understanding of structural geology as a whole and of the cause of earthquakes and the like in particular.

The Florida Ship Canal

Allen S. Park



ON THE CANAL ROUTE

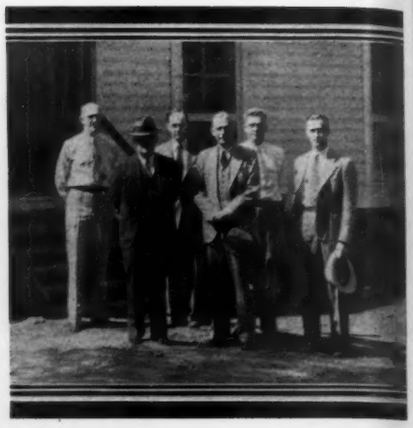
Florida is a land of plenty, so far as water is concerned. The peninsular plateau is like a great saturated sponge, and the surplus of the annual 53-inch rainfall that cannot be absorbed or retained gushes forth as springs, runs off as broad, lazy rivers, or accumulates as lakes. Silver Springs, near Ocala (above, left), is so large that it immediately forms the sizable Silver River, which is navigable to its head. Measurements of Silver Springs taken during the period 1930-34 indicated a flow ranging from 362,000 to 551,000 gpm. The water wells out into a circular basin having an extreme depth of 81 feet. Glass-bottomed boats afford views of the bed of the pool and of the many varieties of fish in it. The temperature of the water is 72° the year round. The top view shows the Oklawaha River, a few miles of which will be widened and deepened and will constitute a section of the canal. The larger map traces the canal route in detail: the smaller one shows its general location.

ONE of the largest and most ambitious public-works projects in the current program of the Federal Government is the cutting of a ship canal across the northern part of Florida. It contemplates the construction of a 30-foot waterway to provide a short cut for shipping plying between Gulf of Mexico ports and Atlantic Coast and European points. It calls for the spending of some $146,000,000 and for the excavating of twice as much material as was moved to create the Panama Canal.

Although some actual digging has been done and more is underway, only $5,400,000 has been made available, and the letting of contracts for the greater bulk of the work entailed awaits additional financing. Meanwhile, the undertaking has become somewhat of a storm center in Washington, and even the people of Florida are divided in their opinion as to whether they want the canal. President Roosevelt is committed to it, however, and it seems likely at this time that operations will proceed, although the source of the funds remains to be determined. An allotment of $5,000,000 was made by the President on August 30, 1935, from the $4,000,000,000 Emergency Relief Act of 1935 to get the project started. An additional $200,000 was assigned to it on December 31, 1935. Since then Congress has refused to authorize an appropriation of $12,000,000 for the work and, save for a third allotment of $200,000 made by executive order on February 13 of this year, no more funds have been provided.

The projects that obtain money from the Emergency Relief Act fund are supposed to be completed by July 1, 1937, and as this would be impossible in the case of the canal, it may be placed in a different category. One suggested plan is that it be financed from regular annual appropriations for the War Department. Believing that our readers are interested primarily in the engineering and construction aspects of the undertaking, we will assume that work is to go forward and present a general description of the canal as planned, discuss the expected results, and review the chief controversial point that has created uncertainty in the minds of Florida residents as to its desirability.

As an accompanying map shows, the Atlantic-Gulf Ship Canal—to use its official name—will follow a somewhat irregular route from the mouth of the St. Johns River on the east coast to a point near Port Inglis on the west coast. This indirect course was selected in order to take advantage of several natural watercourses. In consequence, only 90 miles of a total length of 195 miles will be entirely artificial canal. The remainder will consist of existing rivers—deepened, and in some cases widened—and of a 19½-mile stretch of channel that will be excavated offshore in the Gulf of Mexico to reach water of the required depth. The principal cities on or near the canal line are Jacksonville, Palatka, Ocala, and Dunnellon. While the waterway will carry some intrastate commerce, most of its freight will be through-



AT CAMP ROOSEVELT

A new camp, named for the President, has been built just outside of Ocala as headquarters for the U. S. Engineer force. Above are barracks housing the workers engaged in clearing land. The canal work is in charge of Lt. Col. Brehon Somervell, district engineer, who is shown in the small picture with some of his staff and with Maj. Gen. E. M. Markham, chief of engineers. From left to right: Clarence E. Boesch, chief of engineering division; General Markham; Capt. Richard Lee, chief of administrative division; Colonel Somervell; Capt. James B. Newman, Jr., chief of operations division; and Capt. Edmond H. Levy, executive officer.

bound, and it is not expected that the canal will materially change the handling of shipments within the state lines.

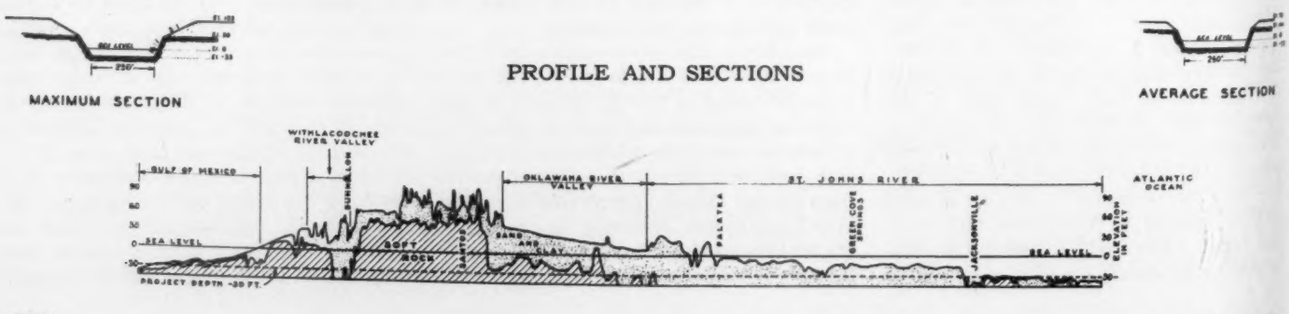
The chief benefit claimed for the canal will be the speeding up of traffic to and from Gulf Coast points which must now round the tip of Florida. It has been computed that it will reduce the passage time of such vessels by from one to three days and save $6,500,000 in their annual aggregate operating costs. Aside from this monetary advantage, the by-pass will enable those ships to avoid the hurricane belt and the dangerous reefs that must now be traversed via the Florida Straits. The canal will form a connecting link between the Atlantic Intracoastal Waterway and the proposed extension of the Gulf Intracoastal Waterway, thereby eventually providing a protected inland route from Boston to Texas. For some shipping it will serve as a third route to the Panama Canal. Furthermore, it is contended that the canal will stimulate the growth of commerce, lead to some reductions in mail and freight rates, and aid military and naval maneuvers in the event of war. Of immediate importance is the fact that the project will create jobs.

The minimum water depth will be 30 feet, with overdepths of 2 feet in earth sections and 3 feet in rock sections, which will make it possible for 94½ per cent of the vessels now in the Gulf Coast service to use the canal. The designed minimum bottom width of 250 feet will enable ships to pass each other at any point, and turning basins are to be established at three places. As a sea-level alignment is planned, there will be no necessity for locks, and delays in passage incident thereto will be eliminated. Channel markers, lights, and a dispatching system will permit 24-hour operation. Based on estimated permissible speeds of 7 knots in cut sections and 11 knots in open-water channels, the average vessel will be able to make the crossing from deep water to deep water in about 25 hours. Traffic surveys indicate that approximately 800 vessels can normally be expected to use the canal every month, or an average of one every 54 minutes. It is not intended to charge tolls.

The idea of such a canal is not new, having been first advanced around 1600, when the Spanish ruled the area that now includes Florida. The French revived the plan when they acquired control, and went so far as to make surveys. The United States began thinking about a canal more than a century ago, and in 1830 the Board of Internal Improvement surveyed a route, but reached the conclusion that the cost of construction would be prohibitive. From time to time the scheme received further attention, but never got beyond the blueprint stage. The surveys and engineering studies that form the basis for the current operations were started by the Corps of Engineers, U. S. Army, in 1927. All told, 28 possible routes were considered before the course was definitely laid out.

The indecision of the people of Florida as to the canal is largely a matter of intersectional difference. It centers around the possible effect that a cut 30 feet below sea level will have on the water supply of that portion of the peninsula lying south of the canal line. Within that area is most of the great orchard and truck-garden acreage, and also such important cities as Miami, Palm Beach, St. Petersburg, Tampa, and scores of lesser communities that would, admittedly, suffer greatly as tourist and industrial centers in the event of a shortage of fresh water.

Water for irrigation and for domestic purposes is drawn from both surface and underground sources, and there have been fears that the supply might be seriously re-



LAND CLEARING

Government-employed labor forces denude the terrain of all heavy growth before they begin to excavate. A total of 26,000 acres will have to be cleared. Because of the nature of the work, manual methods predominate, but skid-mounted gasoline engines are used to supply power for pulling out stumps in marshy land (left). As these pictures indicate, marked differences in the character and abundance of the vegetation are to be noted within short stretches. Typical trees are pines and palms, the former growing where the topsoil consists mostly of sand.

duced, or perhaps even stopped, if the subsurface rocks were cut through by such a waterway. Similarly there have been misgivings that the gash would permit salt water from the ocean and gulf to permeate the underground rock structure and render its discharge brackish. In an attempt to determine just what would happen, numerous investigations have been conducted and a sizable pile of reports has been accumulated. They are not entirely in accord, and consequently there exists a confusion of ideas on the subject. The Army Engineers contend, however, that there is no need for alarm, and in support of that stand they cite an interim report made on December 18, 1935, by a special board of geologists and engineers that was engaged in studying all available data, including the reports previously issued. The personnel of that board, consisting of four members of the U. S. Engineer Corps and one civilian, is: Clarence E. Boesch, head engineer; Sidney Paige, senior geologist; Frank C. Carey, principal engineer; E. B. Burwell, geologist; and Malcolm Pirnie, New York consulting engineer. The following discussion of the question under consideration is based on that report.

The Florida Peninsula, a nearly flat plateau, is underlain by gently arched sedimentary strata. Those just below the surface are sands, clays, marls, and sandy limestones. Their porosity is not high, but beneath them is a series which consists largely of a very porous limestone. These two groups of deposits have a thickness of about 4,000 feet. The crest of the arch is in the northwestern part of the state, and at that structural high point the upper series has been worn away by erosion, leaving the underlying limestone exposed throughout an oval-shaped area 120 miles long and 50 miles wide.

The rainfall averages about 52 inches annually, which is equal to 900,000,000 gallons per square mile. A large proportion of this precipitation is absorbed. It seeps down through the upper, denser strata, and into the more open limestone underneath. As a result, a great underground fresh-water reservoir has been formed. The unabsorbable surplus runs off as rivers and accumulates as lakes. As an evidence of the present abundance of surface water in Florida, it may be mentioned that there are some 30,000 fresh-water lakes. The surface drainage pattern is controlled largely by two areas which rise above the general level of the plateau. One of these is near Lakeland, in Polk County, about 75 miles south of the canal route. From it, streams flow northward, westward, and southward. The second is in Putnam County, about 40 miles north of the canal line. Streams flow from it in all four directions. Between these elevated sections is generally lower ground, and it is this ground that the canal route traverses. Near Ocala there is a divide which separates the eastward flowing Oklawaha River from the westward flowing Withlacoochee.

Aside from the surface streams there is a well-developed underground drainage system. Channels which have been cut in the porous limestone in the course of millions of years carry these subterranean rivers. Some of them discharge at the surface in the form of springs. As the water table conforms largely to the surface topography, its two high points correspond to the elevations previously mentioned, and the underground flow tends to follow the same pattern as the surface run-off. This means that some of these subsurface streams converge upon the low section crossed by the canal route. As a result there exists along that general line a group of amazing springs such as Silver Springs, Blue Springs, and Homosassa Springs, the first of which is reputed to be the largest in the world. From this it is apparent that much of the water that some people fear might be drained from the ground by the canal cut is already running off in the form of both surface and underground flows. In other words, it is surplus water that the ground cannot absorb or cannot retain when it does absorb it.

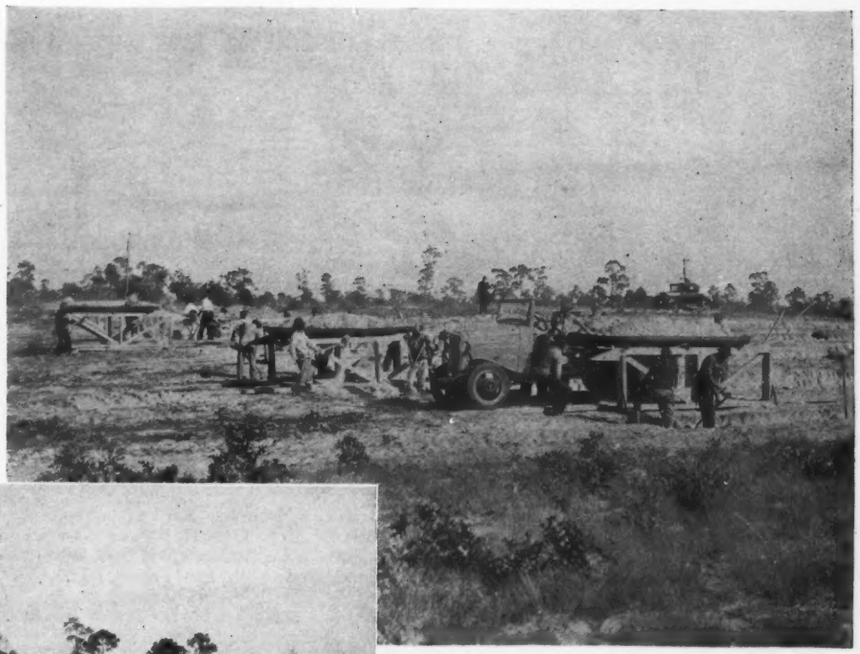
The next point involved is whether or not the canal would lower the ground-water level to a dangerous point. Investigations indicate that the fresh-water reservoir is deep seated, and that it floats upon a salt-water reservoir that permeates the underlying rocks. The fresh water has depressed this salt water below sea level to depths that vary according to the height of the fresh-water table above sea level. It has been computed that for every foot of fresh water above sea level there are 38 feet of fresh water below sea level, the ratio between the two being controlled by the ratio between the specific gravities of fresh and salt water.

It is evident that before the ground-water level could be materially lowered throughout a large area it would be necessary to absorb all the present surface flow, including not only the rivers that are fed by run-off water but also those that are fed by the great springs which emanate from the subterranean streams. As the rainfall is sufficient to maintain the ground at a point of virtual saturation, the investiga-

METHODS OF EXCAVATI

A great variety of mechanical dirt-m equipment is utilized by the differen tractors. Some rely on tractors and w or tractors drawing 10- and 12-cubic scrapers that scoop up their own loads of which types are shown at the left. (are employing belt conveyors with sl to pile the material on the spoil ban illustrated just below. One contractor u dirt in side-dump railroad cars drawn gasoline locomotive (opposite page). ingenious of all is the "Chambers Ba illustrated at the bottom of this page, was devised by a member of one of th tracting firms. The material is loade dragline into a hopper that empties 12-cubic-yard car that runs on ove rails within a structural-steel tunne

discharges at the far end on to the spoil area. The car is operated by electricity, the current being taken from a trolley on either side of its runway. The entire assembly is supported by means of a centrally disposed tower that is mounted on crawlers by which the structure can be moved by electric power along the canal line, as desired. The discharge end can be tilted to permit dumping on a growing pile. So that the specified number of men shall be employed, shovel brigades augment the mechanical apparatus. Removable truck bodies are loaded as they rest on timber framework. When filled, the trucks back under them and take them away for dumping. This expedient greatly cuts the idle truck time. At the right is such a truck picking up its load, while two detached bodies are being filled by shovelers.



tors hold that there is no sound basis for the fear that this might happen. In fact, they go so far as to express the belief that the precipitation will hold the ground water at its present level, except in a limited area near the canal, and also support the surface run-off as it now exists, despite any losses suffered from discharges into the canal at or below sea level. However, they admit that in some sections, specifically along 27 miles of the route, the ground-water level would probably be lowered immediately adjacent to the canal, but they contend that it would be unaffected at distances of from 10 to 15 miles. Within the local area, it is predicted, shallow farm wells would have to be deepened.

The report is reassuring as regards any detrimental effect upon agriculture, stating: "Forests grow, crops are cultivated, and orange groves thrive on land under which the water table may be 60 to 100 feet below the surface. Lowering the water table further will not affect this condition. Crops draw their nourishment from the rainfall as it wets the ground, and will do so in the future."

The possibility of municipal water supplies being jeopardized is also held to be of no consequence. Ocala, the largest city contiguous to the open canal, draws its water from a depth of 225 feet below sea level. The report states that the fresh-water reservoir in that area extends to a depth of 1,600 feet below sea level, so that the water table might be materially lowered without cutting off the supply. The opinion is expressed that the supplies of other cities would be unaffected. Much stress has been laid on the importance of the so-called Ocala limestone as a water carrier. It is brought out, however, that around Miami, for instance, this limestone is 1,000 feet under the surface and contains salt water, whereas the city's domestic supply is obtained from rocks which are just below the surface and which derive their moisture content from local rainfall. Similarly, it is set forth that there can be no possible connection between the supplies of other southern Florida cities and the cutting of a canal many miles away.

In addition to the open ground-water reservoir previously discussed, there is in some areas a deeper-lying, closed reservoir which is the source of supply for artesian wells. It is conceded that the lowering of the ground-water table in the canal zone would reduce the pressure upon the artesian reservoir near the canal and, consequently, diminish the flow from wells of that class. However. the area that would be affected is already one of relatively low pressure. As exploratory drilling is now in progress, the board has reserved a detailed opinion on this phase of the question until more facts are available. And according to the board, salt water, which may flow into the canal from the ocean and gulf ends or from below, cannot possibly get into the underground fresh-water reservoir and contaminate it. This would be prevented, it is stated, by a continual discharge of fresh water into the canal.

To insure a regulated flow of surface water into the canal, it is proposed to build four spillwater-dam reservoirs on streams adjacent to the canal. Such water would normally flow toward both ends of the canal, and thereby serve to keep salt water out. In connection with these retention reservoirs it may be possible to generate relatively small amounts of hydro-electric power.

The digging of the canal constitutes the largest excavation job ever attempted. It calls for the removal of 401,985,000 cubic yards of earth and 168,690,000 cubic yards of rock, or a total of 570,675,000 cubic yards, as compared with the 288,000,000 cubic yards handled in the case of the Panama Canal. The rock is confined to the western half of the line, where it is found not only on the peninsula but also on the bed of the gulf. It is the soft, porous limestone that, as was previously mentioned, forms the bottom strata of the two sedimentary series. The canal route traverses the southern part of the area where erosion of the overlying sediments has exposed this lower formation. To reach elevation –33, which the canal bed will follow in rock sections, it will be necessary to cut through this limestone as much as 141 feet at the highest point. It is expected that the inland stretches of the canal will be excavated about 25 per cent in the dry and about 75

WHEN THE DARKIES SMILED

Government men report that the Negroes around Ocala were pretty glum when they saw machinery being moved in to start the work of excavating. But their faces relaxed into broad grins when mules began to arrive, for mule-driving is their specialty in the South and they knew there would be jobs for them. One small item of excavating is being handled by Government forces—with the mules and their dark-skinned pilots very much in evidence.

per cent by dredging. Dredges, drill boats, and other floating equipment will have to be employed for inland wet excavating and also on the 19½-mile section that extends into the gulf.

Ten bridges, with spans ranging from 300 to 540 feet and with clearances of 135 feet above water, will be built over the canal to carry railroads and highways. At various other points crossings will be made by means of ferries. The right of way will be a mile wide, with the canal in the center. Twenty-six thousand acres of land will have to be cleared. It is estimated that six years will be required to complete the undertaking.

For purposes of construction, the route from Jacksonville to the gulf has been divided into four areas, ranging in length from 25 miles to 68 miles. These are shown on an accompanying map. The present 30-foot, St. Johns River stretch between Jacksonville and the ocean is in charge of the U. S. Engineer office at Jacksonville. The Palatka area extends along the St. Johns River from Jacksonville to the Oklawaha River beyond Palatka, a distance of almost 70 miles. Ocean ships can now enter Jacksonville Harbor, but from that point to Palatka, 51.83 miles, the present channel has a minimum depth of only 13 feet. Throughout these two sections the channel will have a bottom width of 400 feet. Continuing westward, the line will follow the Oklawaha River Valley, and for a few miles the stream itself. It will next cut through the divide to the Withlacoochee River, partly following the valley and partly the stream from Dunnellon to a point near Port Inglis. Entering the Gulf of Mexico the channel will be excavated to a bottom width of 500 feet for 16 miles and to 1,000 feet for the final 3½ miles necessary to reach deep water.

Construction operations are in charge of the Corps of Engineers, U. S. Army. A new engineer district has been created to handle the project, with Lt. Col. Brehon Somervell as district engineer. Headquarters have been established just outside of Ocala, where Camp Roosevelt has been built to house the administrative and engineering offices. The work thus far started is concentrated within the area adjacent to Ocala. The first allotment of $5,200,000 is being spent as follows: Clearing land, $500,000; bridge foundations, $500,000; housing, shops, and minor structures, $500,000; excavating, $3,700,000.

It is the intention to let contracts for the major items of the undertaking, including excavating and bridge building. Land clearing will be done by forces directly under the U. S. Engineers. It is expected that there will be work for 20,000 or more men when operations are at their height.

Little time was lost in putting the project underway. The first money was made available on September 3, and work was begun two days later. Within a few weeks there had been approved seven contracts and two subcontracts calling for the excavation of 13,500,000 cubic yards of dirt, and one contract for bridge foundations. These activities extend along a few miles of the canal line just south and west of Ocala. Rapid progress is being made on these contracts.

Although the operations are to be conducted so that a specified number of men shall be employed, the contractors have introduced various modern mechanical methods and equipment for moving large quantities of earth to the spoil banks. Among them are a railroad, belt conveyors, scrapers, tractors and wagons, and a novel self-contained, portable apparatus known as the "Chambers Bridge." Typical equipment is shown in accompanying pictures. In addition to the contract work, the Government is excavating 192,000 cubic yards by force account. Mules and scrapers have been temporarily used on this job to increase employment. The average cost under the first contracts is 21.7 cents per cubic yard; but when the work is under full headway, with larger contracts in force, it is expected that dirt will be handled for about eight cents per cubic yard.

Following is a list of the contractors, the amount of each award, the principal kinds of equipment being used, and the daily average progress made by each.

Blythe Bros., Boyle & Fuller, Barnwell, S. C., $202,084. Operating draglines, trucks, and scrapers. Average daily output, 5,600 cu. yds.

Badgett Construction Co., Memphis, Tenn., and Boone & Wester, Cairo, Ill. (subcontractor), $274,390. Operating belt conveyor, draglines, tractor and wagon units. Average daily output, 11,000 cu. yds.

George S. Funk & Stevenson Co., Clarksdale, Miss., $196,320. Operating draglines, trucks, tractor and wagon units. Average daily output, 8,000 cu. yds.

Hooper Construction Co., Bunnell, Fla., $123,740. Operating draglines, trucks, tractor and scraper units. Average daily output, 4,500 cu. yds.

Lewis-Chambers Construction Co., New Orleans, La., $386,040. Operating draglines, bridge conveyor, trucks. Average daily output, 15,000 cu. yds.

Harvey, Ray & Noonan, Pensacola, Fla., $405,930. Operating draglines, belt conveyor, tractor and wagon units. Average daily output, 10,500 cu. yds.

Benjamin Foster Co., Philadelphia, Pa., $1,024,056. Operating draglines, tractor scrapers, trucks. Average daily output, 28,000 cu. yds.

Brooks-Callaway Co., Atlanta, Ga., (subcontractor), $212,938. Operating draglines, tractor and wagon units. Average daily output, 7,400 cu. yds.

George D. Auchter Co., Jacksonville, Fla., $114,480. Operating draglines, trucks, industrial railway. Average daily output, 4,600 cu. yds.

Contractor for bridge foundations, M. J. Carroll, Inc., Ocala, Fla., $91,300.

All labor, other than that classed as technical and clerical, is being supplied through the Works Progress Administration. The usual scale of wages for relief work is being paid the 950 men in the Government's hired labor groups. Minimum wages paid by contractors range from 30 cents to $1 an hour, depending upon the nature of the service performed. Total employment is about 6,600.

Assisting Lt. Col. Somervell in supervising the operations are four U. S. Engineer officers and one civilian engineer. They are Capt. Edmond H. Levy, executive officer; Clarence E. Boesch, chief of the engineering division; Capt. James B. Newman, Jr., chief of the operations division; Capt. Richard Lee, chief of the administrative division; and Capt. H. J. Banton, chief of the medical and sanitary division.

Tunneling Innovations at Fort Peck Dam

DRILLING

In enlarging each centrally placed 14x15-foot pilot bore to the full-sized circular section of 32 feet 2 inches, the entire heading face is drilled and blasted in one operation. The relatively soft shale is easily drilled with "Jackhamers" using auger steel. Four machines are run simultaneously, two from the extensible working platforms of the "jumbo" and two from the floor of the tunnel line. The driller shown here is standing on one of the rails on which the jumbo travels.

J. D. Jacobs

MUCH has been learned about the art of tunneling during the 34 centuries that have gone since the early Egyptians began crudely and laboriously to hew passageways through the rocks of the earth to build sepulchers for their Pharaohs. Certainly the ultra-modern methods being applied by the excavators of the diversion tunnels for the Fort Peck Dam are not in the least like those used by their ancient predecessors. But it can be safely said that few other underground achievements since man began to burrow in the earth have taxed to a greater extent the ingenuity of those responsible for them.

The four huge conduits which will conduct the Missouri River around the dam while it is being built and which will afterwards control the discharge from its reservoir are scheduled to be put to use in the summer of 1937. By the time water is finally turned through them, more than three years will have been spent in their construction. The Fort Peck Project, which includes the world's largest earth-fill dam, has been previously described in these pages; but it will clarify the present account briefly to review the salient features of the undertaking of which the tunnels are so important a part.

Being built by the Corps of Engineers, U. S. Army, as PWA Project No. 30, the dam will regulate the widely fluctuating discharge of the upper Missouri, resulting in the maintenance of a navigable 8-9 foot channel between Sioux City, Iowa, and the confluence of that stream with the Mississippi. Flood control, irrigation, and power will be incidental benefits. As with all PWA work, Fort Peck was also approved as an employment measure. During the peaks of operation in both 1934 and 1935 more than 7,000 men were on the job, and the number has not fallen below 4,000 since May, 1934.

The dam will be composed of 100,000,000 cubic yards of alluvial material pumped into place by hydraulic dredges, will rise to a maximum height of 242 feet above the present river bed, and the main portion of its base will have a length of 8,000 feet and an over-all width of 2,950 feet. The total length of the crest, including an 11,500-foot dike section extending westward from the left abutment, will be nearly 4 miles. Back of this man-made mountain will be impounded a veritable inland sea 180 miles long and 16 miles across where it is widest.

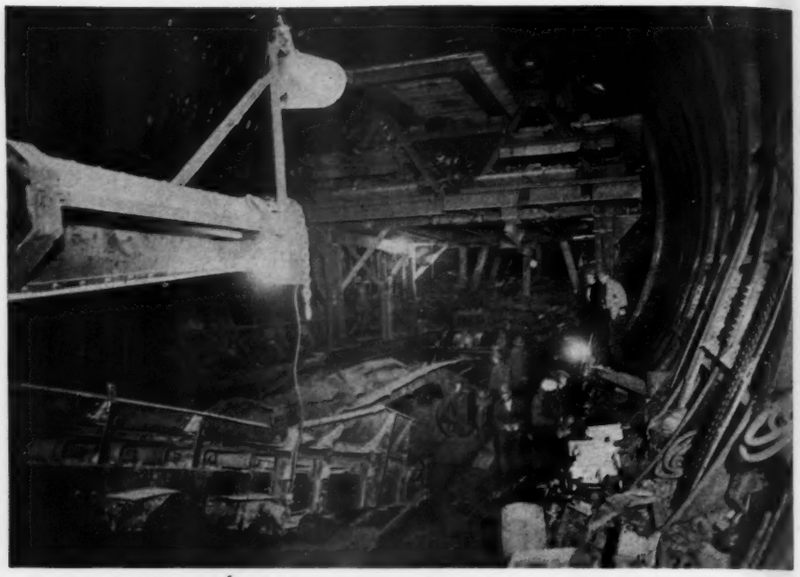
The average year-round stream flow at Fort Peck is 8,000 second-feet. In June, 1908, the greatest flood on record occurred at this point, at which time the discharge reached about 154,000 second-feet. The tunnels are designed to pass about 65,000 second-feet from the filled reservoir; and in seasons of excessive floods, when the water entering the lake over an appreciable period amounts to more than that, the surplus will overflow down a concrete spillway channel built through a gap in the hills 3 miles east of the dam.

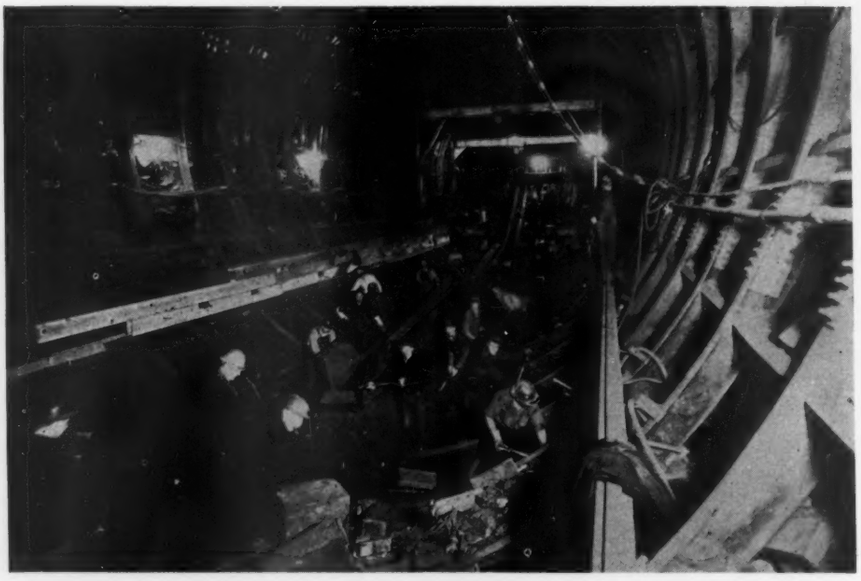
The four diversion tunnels, spaced 125 feet center to center, penetrate the bluff that forms the eastern wall of the valley at a point about 1,000 feet upstream from the toe of the dam. Swinging northward in a long curve, they pass under the east abutment, enter a 1,900-foot tangent, and then curve again to the west to emerge below the dam in a concrete-lined outlet channel leading back to the river bed. They vary in length from 5,386 feet to 7,260 feet, averaging 6,323 feet each. The tunnels are all circular in cross section and will have finished inside diameters of 24 feet 8 inches. The concrete linings will be from 36 to 45 inches thick and will contain steel reinforcing bars as a means of resisting internal water pressure. Tunnel No. 1, the shortest, will be used as a power penstock; and that part of it extending from the control shafts to the outlet portal will be constructed with an inner steel-plate shell of varying thickness.

The inlet portals of the tunnels consist of a massive reinforced-concrete retaining wall, 525 feet in length and 85 feet in over-all height. The vertical portion of this wall is 22 feet thick, and it is probably one of the most heavily reinforced structures of its kind ever designed. Instead of the customary standard steel rods, its main reinforcing members are two vertical rows of 10-inch steel beams spaced no farther apart than is necessary to allow the concrete to be placed between them. This unusual reinforcing serves to provide a high factor

MUCKING

At first glance the tunnel at the right might be mistaken for a subaqueous bore. The circular steel ribs, which remotely resemble lining segments, support the unstable shale until the concrete lining can be poured. In the background is the jumbo that gives access to the drilling face and facilitates the erection of the steel. Beneath it a Conway mucker is feeding spoil on to the belt conveyor which carries it to a hopper from which it is dropped into cars. Leaning against the tunnel side at the right are lengths of auger steel with which the drilling is done. For about 150 feet back from the heading there is left on the tunnel floor 18 inches of loose muck to form a base for the haulage railroad. As the face is advanced, a crew removes this bottom material, sweeps the shale and paints it to prevent slacking, and then places the reinforcing steel preparatory to pouring the invert. The view below shows the muck being shoveled on to a portable belt conveyor for transfer to cars. So as not to interrupt traffic to and from the heading, this cleaning up proceeds quickly, after which the rails, which have to be taken up for the purpose, are relaid on a light steel bridge. On either side are the rails on which the jumbos and gantries run.





of safety to obviate the possibility of a landslide obstructing the entrances of the tunnels after they are submerged under 200 feet of water. Over the portals there will be erected a trash-rack structure of steel and concrete to prevent debris from being carried by the current into the mechanism of the control gates.

Where the tunnels pass under the axis of the dam are located the control-gate shafts, which extend 260 feet from the hilltop to the tunnels below. Each tunnel passes through two shafts: an emergency gate shaft rectangular in plan, and, 72 feet downstream from it, a circular main shaft 50 feet in diameter. In the chambers created by these shafts will be installed the control mechanisms. The operating machinery will be housed in buildings constructed over the tops of the shafts.

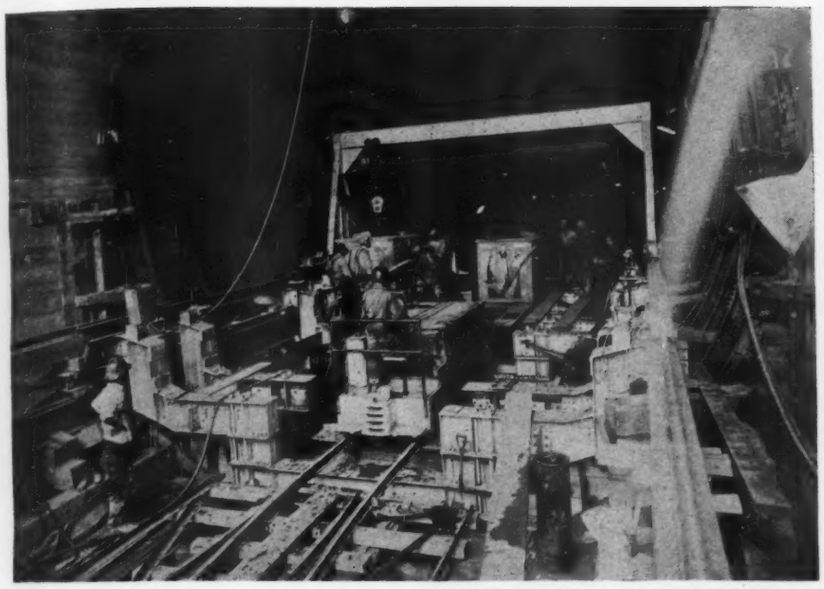
One of the most serious problems faced by the construction engineers at the start of the job was that presented by the nature of the rock formation through which the tunnels were to be driven. The Fort Peck region is in the outcrop belt of a sedimentary deposit known as Bearpaw shale. This rock is soft and heavy, easily drilled, and can be blasted with very small charges of explosives. The principal construction difficulty, from the miner's standpoint, is that the shale is not structurally strong enough to stand unsupported as a tunnel roof. Consequently, it is necessary to install circular steel supports or ring beams throughout the tunnels to hold the roof until the concrete lining is placed.

Another peculiarity of Bearpaw shale is that it has a high moisture content which escapes upon exposure to dry air, resulting in rapid disintegration. To counteract this destructive action, the shale, immediately upon being exposed, is painted with a bituminous sealing solution applied by pneumatic spray guns. As a further precaution, the air within the tunnels is maintained at a relative humidity of 90 per cent. Compressed air is used to atomize water through spray nozzles to assure a continuous output of vapor.

Work on the tunnels was begun in May, 1934. Before any underground operations could be started, access pits at the intake and outlet had to be dug with power shovels. Nearly 2,000,000 cubic yards of open-cut excavation was removed in 1934, and an additional 600,000 cubic yards must be handled before the river can run through the tunnels.

Before the construction of the final tunnel section could be undertaken it was necessary to complete the driving of pilot drifts along the center lines of the main tunnels. These pioneers are 15 feet wide and 14 feet high, with arched roofs supported by standard segmental tunnel bents of 10x10 timbers. The pilot tunnels were finished in the spring of 1935, and by the following July the open-cut work at the outlet portals had reached a stage where the operation of enlarging them to the full diameter could be begun. By February 1, 1936, the main tunnels had been advanced 8,280 feet, or approximately one-third of the total footage. The enlarging work is progressing from the outlet portals toward the inlets at an average rate of about 15 feet per tunnel per day.

Seldom does one observe a construction job on which the sequence of operations and the step-by-step production are as scientifically organized as they are on this one. Taking a tip from modern factory-production methods, the tunnels are being built in eight consecutive stages. These, in their proper order, are: excavating and placing of steel bracing—a cycle operation which can be classed as one step; welding of steel supports; hand cleaning of the tunnel floor; placing of reinforcing steel for the invert; pouring of the invert concrete; placing of reinforcing for the sides and arch; completion of the concrete shell; and pres-



CONCRETING OPERATIONS

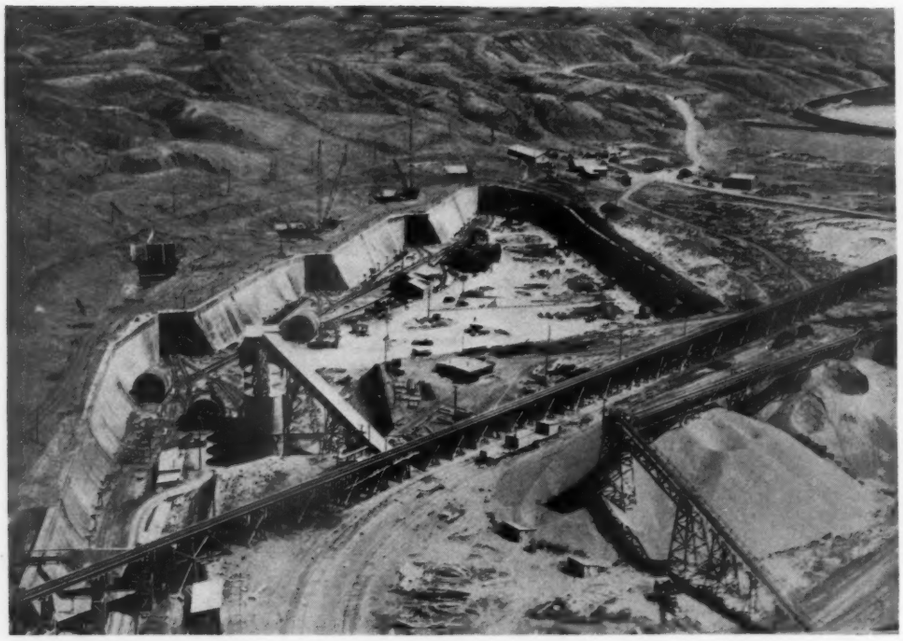
From 36 to 45 inches of concrete is placed as a permanent lining, being reinforced with heavy bars in addition to the bracing rings used to support the shale during the preliminary operations. The invert is poured with the aid of a steel gantry (left) that carries the tracks used by the cars that haul muck out and concrete in. For the central section of the tunnel line, concrete is dumped directly through the bottom of the car without lifting the bucket in which it is delivered. To reach the sides, the 2-cubic-yard bucket is handled by an electric hoist that moves laterally on the overhead gantry beam. Side-wall and arch concrete is placed pneumatically, as shown below. The cars at the left carry buckets of concrete, the forward one of which is being raised to a hopper that feeds it to one of the two Press-Weld placing machines. Compressed air under sufficient pressure to apply the concrete is stored in the receiver mounted across the upper part of the gantry. The air supply hose extends downward at the right. A close-up of one of the placing machines is shown at the bottom. The concrete is "shot" upward to trap doors in the forms through the 8-inch flexible hose lines at the lower left.

sure grouting of the roof of the tunnel to fill the voids which remain between the concrete and shale. All these operations must be carefully timed to proceed simultaneously at the same average rate of speed. The final step follows 800 to 1,000 feet behind the heading operation.

Each of these construction stages is mechanized to the fullest possible extent. Machinery is carried on specially designed traveling platforms or gantries—the eight steps requiring the use in each tunnel of thirteen gantries, most of them as high as a 2-story house and equipped with flanged wheels to travel on rails supported on brackets along the sides of the tunnel. The gantry legs straddle 36-inch-gauge railway tracks with ample clearance to allow for the 2-way passage under them of electric trains.

The leader of the underground procession of traveling machines is the mucking jumbo. The term "jumbo", common in the tunnelman's vernacular, is quite appropriate in this case. An accompanying illustration gives the reader a good conception of its size and its sturdy construction, which are necessary in order that it may withstand the battering it receives from each blast set off ahead of it. The jumbo is provided with five extensible platforms from which the men can operate pneumatic tools for trimming the roof and sides and from which, also, the steel supports can be placed and bolted. These platforms are actuated by compressed-air cylinders manipulated by control valves at the base of the machine.

Hand-held "Jackhamers", using 1½-inch auger drill steel, bore the holes for blasting. The holes are drilled perpendicular to the face and parallel with the axis of the tunnel. Four drills are usually run simultaneously, two from the overhead platforms of the jumbo and two from the floor of the invert. An average round consists of 44 holes, 28 of which are "rib" holes,



DOWNSTREAM PORTALS

Tunnel-enlargement operations are being conducted from this end. The outlets of the four bores, 125 feet apart, emerge here into what will eventually be a concrete-lined channel leading to the river. This picture, taken before the start of concreting, shows some of the barrel-like forms that are used in this work. Across the trestle, at the left, is the concrete-mixing plant with the storage silos into which cement is loaded pneumatically directly from cars. At the lower right are the aggregate stock piles with the discharge end of the belt-conveyor system that delivers the materials. Other conveyors transfer them through tunnels to the mixing plant.

spaced around the circumference of the tunnel. The sixteen others are "relievers" and are spaced between the periphery and the pilot-tunnel opening in the center. In average ground or better, the advance per round of drilling and blasting is 5 feet, which is the standard spacing of supporting ring beams. In bad ground, or through fault zones, this spacing is reduced to 3½ feet, and the depth of drilling is decreased accordingly. When the drilling has been finished, the holes are loaded and wired to be detonated electrically from a locked firing switch located several hundred feet ahead in the pilot tunnel. The switch is not closed, of course, until all workmen have retreated to a safe distance.

Clearing the air of fumes following a blast is done rapidly because of the size of the bore and the presence of the pilot tunnel through which a fan draws the stale air to be exhausted up the shafts. Ventilation is further hastened by the customary procedure of bleeding the air line in the vicinity of the muck pile for a minute or two after each blast.

The material brought down by blasting is removed by the aid of a standard Conway shovel. For the benefit of those not familiar with the operation of one of these excavators it may be said that the machine runs on the 36-inch-gauge track, scooping up muck ahead of it into a trough-shaped dipper which tilts and slides its load back on to a self-contained conveyor belt which, in turn, carries it to a muck car or other receiver behind it. Heretofore the customary tunnel practice has been to load one car at a time, stopping the shovel while the full car is being replaced with an empty. The delay in thus switching cars has been eliminated at Fort Peck by the use of a gantry loading conveyor. This machine consists of a long belt, above and parallel with the track, under which a train of five cars can be backed and loaded by pulling the empties forward one at a time. The Conway drops its muck into a hopper on the front end of the gantry belt.

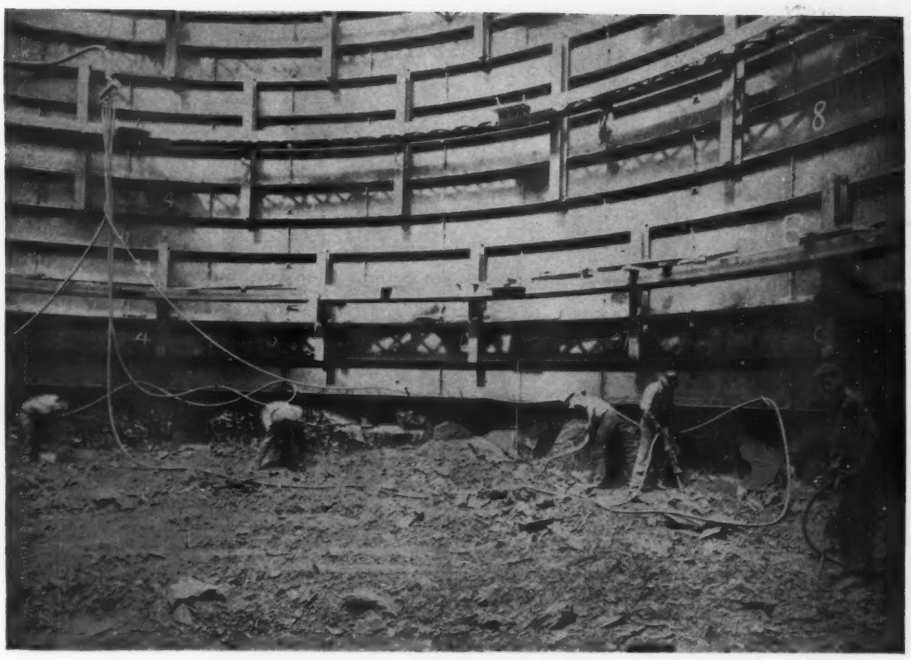
To drill, shoot, and muck out a round ordinarily requires an 8-hour shift, but on several occasions, when good ground was being penetrated and other conditions were favorable, four complete rounds and more have been made in a 3-shift period of 24 hours. The steel supporting rings are erected as soon as mucking is completed and the roof, sides, and bottom can be trimmed to shape with air tools. Most of the trimming is done with Ingersoll-Rand CA-35 paving breakers using bull-point steel. For lighter work, a few L-54 paving breakers are in service. The rings—standard I-beams rolled to proper curvature—are made up of five segments which are connected and spaced by 26 longitudinal purlins. Initial assembly is by bolting, expedited by means of air wrenches. Conventional torque wrenches are used for running up the nuts, but an order has been placed for several of the newly introduced Pott impact-type wrenches with the expectation of employing them to speed up this operation. The bolted joints are subsequently welded, steel supports acting as tension members and supplementing the reinforcing bars in the concrete lining. To enable the welders to reach all parts of the steel rings, the motor-generator welding sets are carried on a platform gantry which closely follows the gantry conveyor previously mentioned.

To form a bed for the narrow-gauge tracks, 18 inches of loose muck must be left in the bottom of the tunnel for a distance of about 150 feet behind the heading. Before the invert concrete can be poured, this material has to be cleared away and the shale swept clean and repainted to obtain a firm bearing surface for the concrete. Since the invert mucking operation calls for the temporary removal of the railroad track, the work must be done with dispatch to minimize delay in traffic to the heading.

This final clean-up is necessarily a hand-shoveling job; but the muck is ingeniously disposed of by the use of a series of portable electric belt conveyors traveling along the floor. Upon these the dirt is deposited and carried back to a muck car on the track. As soon as the bottom has been thoroughly cleaned, the track is laid on a light steel bridge beneath which semicircular sections of steel reinforcing bars can be placed and tied preparatory to pouring concrete.

The concrete in the invert, or bottom quarter of the circle, is poured 250 feet to 300 feet behind the heading. A movable steel structure, which carries the steel plates that form the invert, runs on the same set of side rails used by the gantries ahead of it. It is 70 feet long and consists of five 14-foot sections flexibly connected for pouring the curves. The steel-frame members are heavily constructed to support the weight of the railroad traffic which must pass over the form to and from the heading. Concrete is hauled in from the mixing plant in 2-cubic-yard, bottom-dump buckets mounted on flat cars. The center portion is dumped through the open bed of the car without lifting the bucket, but to reach the sides of the form the bucket must be lifted and handled with an overhead electric crane hoist which moves along the length of the form on rails mounted on the form beams.

The next step after the completion of the invert pour is the hanging of the reinforcing bars in the upper three-quarters of the tunnel circle. This is effected with the



EXCAVATING CONTROL SHAFT

Two vertical control shafts extend from the axis of the dam down to each tunnel —a distance of 260 feet. The main shaft is circular and 50 feet in diameter. Seventy-two feet downstream is an emergency shaft that is rectangular in section. The illustration shows one of the circular shafts being excavated with paving breakers. This was done by first sinking an 8x8-foot pilot shaft and then enlarging it by the glory-hole method, using a Caterpillar bulldozer to shove the muck to the opening. Here is pictured the steel lining which, because of the unstable ground, had to be carried downward as sinking progressed.

aid of another traveling gantry equipped with a raisable top frame upon which the hoops and the longitudinal bars are laid and tied together to form the reinforcing cage. The frame is then lifted with jacks to bring the cage into final position for fastening the bars securely to the ring beams. After that the frame is again lowered to allow the reinforcing gantry to move forward to a new location.

The 70-foot steel forms for pouring the side-wall and arch concrete are built in 14-foot sections like the invert forms. To collapse them for shifting after the concrete has set, they are constructed in three segments—a top section and two side wings hung from it on hinges. To free the form, the side wings are drawn in and the top segment is lowered, all by means of screw jacks. The whole section can then be pulled forward on its trucks and reset for the next pour.

Concrete placing in the arch is done with pneumatic "guns", of which two are used in parallel. These consist of a pressure chamber with a 6-inch pipe outlet at the bottom and an airtight door at the top. The cycle of operations involves feeding concrete through the door valve from a hopper above, closing the door by an air-operated mechanism, and admitting compressed air to the chamber—the pressure forcing the liquid concrete through an 8-inch pipe up to the arch form where it is discharged through trap doors. All concrete, as it is placed either in the invert or in the arch, is thoroughly puddled with pneumatic vibrators to expel entrained air bubbles. A period of 48 hours usually elapses before the concrete is set and the forms are loosened.

It is impossible to place concrete in a tunnel arch without leaving some space between the rock roof and the concrete lining. This cavity must be filled by grouting to prevent the seepage of water along the outside of the tunnel shell. Grout—a rich, thin mortar of fine sand, cement, and water— is injected under pressure through pipes set in holes drilled through the lining. The drilling of these holes is done from a traveling platform gantry. Attached to the latter are adjustable bars on which are carried S-49 "Jackhamers" mounted on screw-feed shells. Holes are drilled wet, using hollow-centered 2⅝-inch 4-point bits.

Apparatus for handling the grout materials and the mixing and placing thereof —including sand and cement bins, two batching scales, a belt conveyor, and two 10-cubic-foot-capacity grout mixers—is all carried on another highly mechanized traveling gantry. An interesting feature of this equipment is that the power used to operate it is compressed air, the conveyor belt and both grout mixers being driven by self-contained air motors.

The foregoing describes briefly the work that goes on underground. Since the tunnels are being constructed concurrently, four identical and complete underground plants, as listed, are required. Space prohibits more than a mention of the extensive outside plant which serves the tunnels. This includes: a modern aggregate and concrete mixing plant, steam heated for winter operation; half a mile of belt conveyor for the disposal of the excavated muck after it has been hauled by the trains out of the tunnels; machine and blacksmith shops; an electric plant with motor-generators for providing direct current for the narrow-gauge railroad; and several miles of narrow-gauge trackage. The compressors that supply the air for the many and varied pneumatic requirements are housed in their own building downstream from the outlet portals. Three Class PRE 2-stage units are in continuous operation. They are driven by synchronous motors with a combined capacity of 900 hp.

Until January 15, 1936, the construction of the Fort Peck tunnels was under contract with the Mason & Walsh Company, a combination of the Silas Mason Company, New York, N. Y., and the Walsh Construction Company, Davenport, Iowa, both well-known contracting firms. It was under the management of this organization that most of the methods described herein were developed. The Mason & Walsh contract covered the placing of a 21-inch concrete lining, the Government's original plan having been to let a second contract for an inner lining in each tunnel after the first had been completed. However, it became apparent late in 1935 that, if the diversion system was to be finished on schedule, the entire lining would have to be placed in one operation. As a satisfactory agreement on unit prices for this work could not be reached, negotiations were entered into between the two parties with the result that the Government, by mutual consent, has taken over the job and is finishing it with hired labor.

Planning and designing of all features of the Fort Peck Project were done in the office of the Missouri River Division of the Army Engineers, located in Kansas City, Mo., with Col. R. C. Moore, Corps of Engineers, as division engineer. Responsibility for construction rests on the Fort Peck District, with Maj. T. B. Larkin, Corps of Engineers, as district engineer. Maj. Clark Kittrell, Corps of Engineers, is in charge of all construction operations, with Capt. A. W. Pence, Corps of Engineers, in direct charge of tunnel operations for the Government. For the contractor, W. A. Durkin was general manager and H. M. Buck job engineer.

Lightning Observatory

ONLY STRUCTURE OF ITS KIND

Situated 102 feet above ground, this lightning observatory at the Pittsfield Works of the General Electric Company was built to supplement the company's field and laboratory work which it has been conducting since 1923.

WHAT is believed to be the only observatory for studying natural lightning has been erected on the roof of the largest building of the Pittsfield, Mass., plant of the General Electric Company. This structure is equipped with a periscope and with a motor-operated, high-speed camera, both of which are designed to cover the entire horizon. There research engineers, under the direction of K. B. McEachron, one of the country's foremost authorities on natural and artificial lightning, expect to obtain information of value to them in their work of improving transmission and distribution equipment so that the far-flung networks carrying light and power into homes and factories may be still further safeguarded from interruption and damage by lightning.

For years the General Electric Company has pursued the study of lightning, both natural and artificial. Its engineers have produced bolts at 10,000,000 volts in the laboratory and studied real discharges from safe distances, all to good effect. But this is the first time they have had a permanent vantage point from which to make their observations. Now, when a thunderstorm breaks in the vicinity of Pittsfield, they can step into a small room in the center of the lofty structure and not only get an unobstructed view of the whole countryside by peering into the eyepiece of the periscope but also take pictures of the electrical display that they can examine at their leisure.

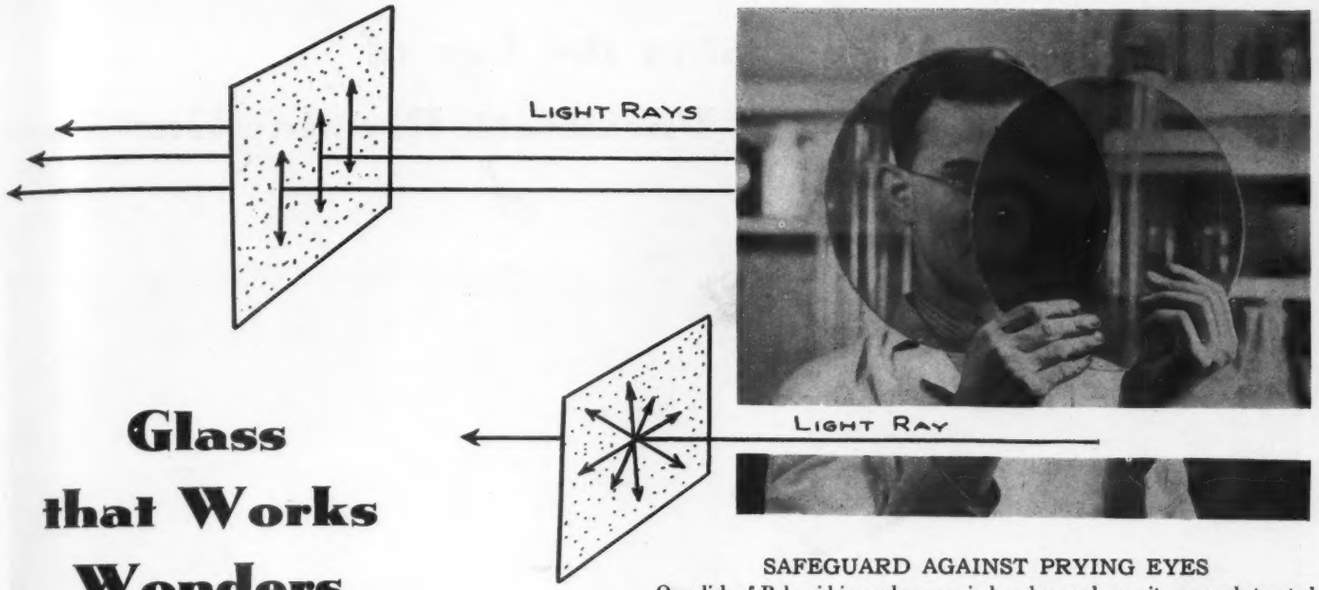
To protect the investigators from lightning, the observatory is constructed largely of metal and is grounded to the steel framework of the building on which it rests. Outside it is coated with aluminum paint and inside with flat black. The structure has a diameter of 14 feet, and in the center of it is the periscope which is topped by an 8-inch crystal sphere. Lightning flashing north, south, east, or west is reflected in the silvery surface of the roof and thence in the crystal sphere, and is made visible through the eyepiece of the periscope by a mirror set at an angle of 45° in its dark-walled tube. The instrument has an effective range of 20 miles. The part of the observatory in which it is set up can be shut off from the rest of it and made light-tight by means of black curtains.

Directly beneath the periscope platform is the camera, which is said to be one of the most unusual apparatus of its kind ever built. It is provided with a moving strip of film and with twelve lenses that make it possible to record all lightning discharges occurring anywhere within its 360° reach. As the instrument is exposed to the weather when in use, it is necessary to protect the lenses against rain, and this is accomplished by surrounding it with a curtain of compressed air. The air required for this purpose is taken from the main line that covers the entire Pittsfield Works, and is admitted into a perforated ring beneath which the camera is placed. The invisible curtain does not interfere with the taking of pictures, and shuts out all but the most severe downpours.

The structure was completed late last fall, but even though the lightning season was well advanced as many as 52 strokes were recorded. Of these 40 were single strokes and the remainder multiple strokes. It was for the purpose of obtaining data regarding the latter that the observatory was primarily built. By its aid, and the extensive field work that is being conducted by the General Electric Company in cooperation with power companies and broadcasting stations, the former's experts hope to be able to give electrical equipment increased resistance to lightning voltages.

LIGHTNING RECORDER

The 12-lens camera, with C. J. Kettler, its designer, at the left, and W. L. Lloyd, Jr., one of the staff of lightning research engineers, at the right. The curtain of compressed air that protects the instrument from rain is lowered from the perforated metal ring below which it is set.



Glass that Works Wonders

SAFEGUARD AGAINST PRYING EYES

One disk of Polaroid is as clear as windowglass and permits an unobstructed view in both directions. But when another disk is held over it so that the polarizing axes are at right angles, as shown in this picture, then the glass appears black and permits vision in but one direction. By simply turning one of the plates it is possible to vary the light at will. In the two drawings, light rays are moving from right to left and impinging upon Polaroid (top) and ordinary glass (bottom). In the case of the former the wave vibrations continue in the same plane: in the case of the latter they are scattered in numerous directions.

GLARELESS automobile headlights have been sought ever since the horseless carriage first made its appearance, and now at last we are informed that they are an accomplished fact. This is a welcome announcement, and traffic experts predict that their use will greatly reduce the 20,000 accidents that are now attributed each year to blinding headlights. Furthermore, they will contribute much to the comforts of night driving, as autoists need hardly be told.

This improvement in headlights is but one of many far-reaching benefits to be derived from a new kind of glass discovered by Edwin H. Land, a Boston scientist. The new product looks like ordinary colorless glass, and the light that has filtered through it appears just like ordinary light. But there the similarity ceases, for Polaroid, as it has been named, polarizes light by simple transmission—that is, it combs out the light rays so that all the wave vibrations are in but one plane in line with the rays and not in many planes at right angles to them, as the accompanying line drawings clearly show. As a result, it is now possible to control the wave-vibration direction of light as easily as the wave length of light. And what is the value of all this?

With Polaroid, scientists have been given, so we are told, a new tool for prying out secrets in many branches of knowledge. It promises important advances in television, photometry, and ophthalmology, as well as in other fields that have remained partly unexplored because of the high cost of the materials hitherto available for polarizing light. In the past, the nicol prism—a specially prepared crystal of Iceland spar—has been the research man's main reliance. However, the useful area of the largest of these prisms in general service is approximately ¾ inch, and this, together with other limitations, has confined its field of application to a few expensive laboratory instruments. Polaroid is at present available in disks about 2, 4, and 10 inches in diameter, as well as in sheets of any desired size. In short, polarized light is no longer a laboratory curiosity, but is now obtainable not only for scientific but also for commercial and industrial uses.

Light that has passed through an optical comb such as Polaroid is said to be plane polarized. Almost all natural crystals form two plane polarized beams moving at different speeds. In what are known as dichroic crystals, one of these beams is absorbed internally to a larger extent than the other, and it is upon minute synthetic crystals of this type that Polaroid depends for its effectiveness. These crystals are suspended in a cellulosic matrix forming a flexible film which is only a few thousandths of an inch thick but which contains as many as 1,000,000,000,000 of the tiny crystals per square inch. In the process of manufacture these are all uniformly placed, lying side by side in the matrix. For this reason, says the inventor, the film is equivalent optically to a large, single crystal.

Facilities for producing Polaroid on a commercial scale have already been provided, and a prominent photographic company is now engaged in building equipment for the projection of 3-dimensional—lifelike—movies, a development that is a direct outcome of the light-polarizing glass. A double camera, with the lenses set as far apart as a human's eyes, will be required to take the pictures, and the spectators will have to look at them through Polaroid glasses. A film of this sort has already been shown as a novelty in some of our movie houses.

The potentialities of this new product of the laboratory are so manifold that it is impossible to go into all of them here. Industrially, it will serve a very useful purpose as a strain tester. A strain tester, according to Mr. Land, operates on a principle well known to physicists—on "the interference color phenomena shown by transparent doubly refracting materials when viewed under polarized light." While this method of testing is not new, it has not been practicable until now to make large-scale observations. Transparent objects such as glassware can be examined directly by means of the tester, and any strains left in them in the course of manufacture will be indicated in brilliant colors. Bridges, airplanes, as well as all manner of machine parts can also be studied for structural weaknesses, but models of them must first be made of celluloid or transparent bakelite. During recent demonstrations of Polaroid at the Waldorf-Astoria, in New York City, a bakelite model of the framework of a building was placed full length in the strain tester. The structure had been twisted as it might be by an earthquake or a hurricane, and when looked at through the glass all the points of strain could be traced without difficulty because they were made plainly visible by bright colors. The value of this is inestimable, for it will help designing engineers to spot defects in structures in advance of their building.

Concerning the Use of Pneumatic Riveting Hammers

RAILWAY WORK

Whether many or only a few rivets have to be driven in the building of bridges or other structures it is generally preferable to use air-operated riveting hammers.

"WHEN only a few rivets are to be replaced, should they be driven by hand? Under what conditions is it worth while to set up a compressor and use a pneumatic hammer? Why?" *Railway Engineering and Maintenance* was recently asked these questions, which were answered as follows by J. E. Bernhardt, bridge engineer, Chicago & Eastern Illinois Railroad, and by P. G. Lang, Jr., engineer of bridges of the Baltimore & Ohio.

In the opinion of Mr. Bernhardt: "Where the rivets to be replaced are few in number fully accessible for hand driving they may be driven by this method. It has been my experience, however, that where only a few rivets must be replaced they are generally located in places where hand driving is extremely difficult. In fact, in many cases hand driving is almost impossible, especially if the rivets to be replaced are in important connections. I prefer to set up a compressor and use a pneumatic riveting hammer, even though there are only a few rivets to be replaced. The reason for this preference is that better rivets result than from hand driving. Where only a very few rivets require replacement, it may be advantageous to use tight-fitting bolts instead of rivets."

"The question," to quote Mr. Lang, "is analogous to many others which are continually arising in modern railway maintenance. Its solution is primarily a matter of balancing the cost of transporting pneumatic equipment and setting it up for operation, against the economies incident to its use. With the practically universal use of pneumatic devices for riveting, the appliances used for manual riveting, simple as they are, are becoming increasingly scarce and difficult to keep readily available. On the other hand, pneumatic appliances designed for other railway work than riveting are frequently adapted for operations of the latter type.

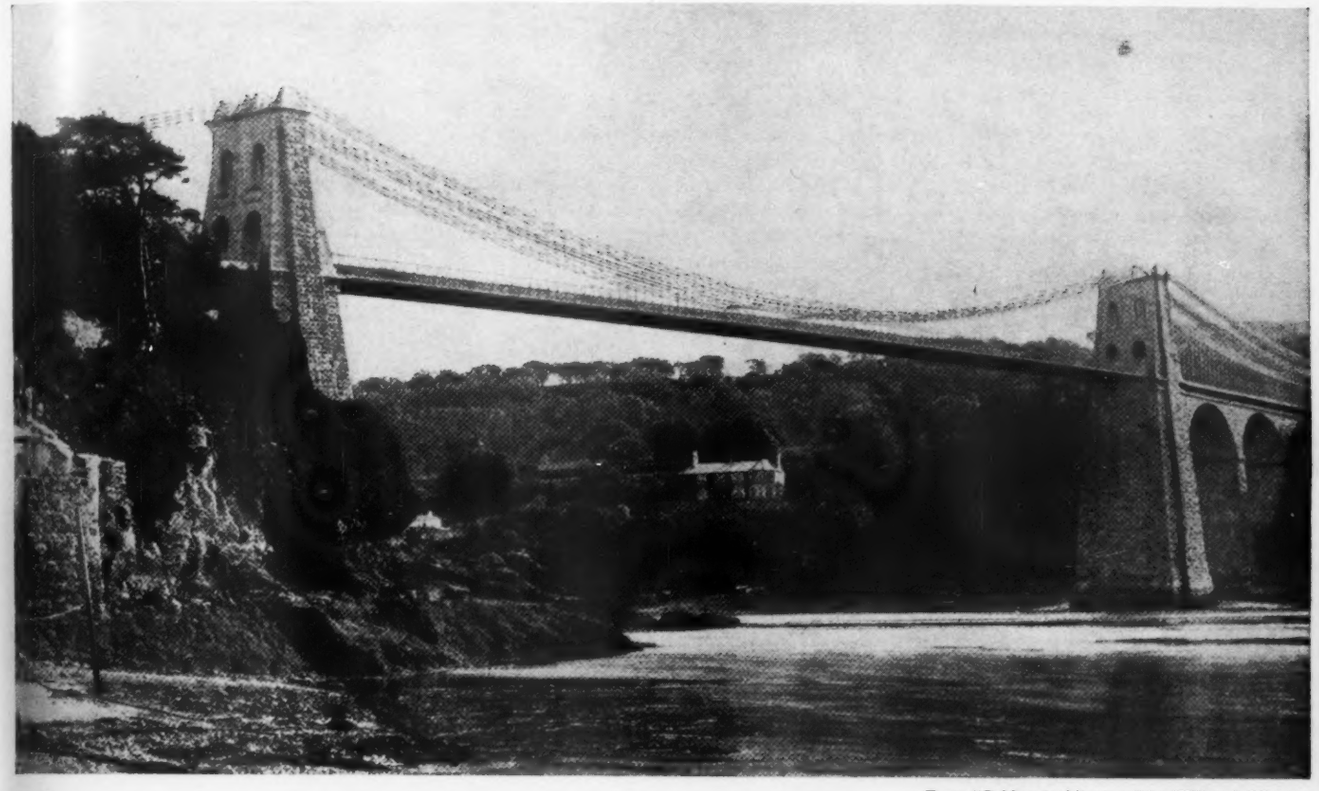
"Such adaptation is facilitated by the extension of power-driven appliances into every branch of maintenance and construction. Air compressors for use in track work are an obvious necessity on all parts of any railway system, and at present there are few points to which it is impracticable to transport such machines within a short time and at moderate cost.

"While the use of pneumatic equipment on the larger projects is undeniably the logical procedure, an attempt to apply general rules to specific conditions, or to establish for the smaller jobs a line of demarcation between the maximum number of rivets for manual riveting and the minimum for pneumatic driving, is extremely difficult. Between the manual maximum and the pneumatic minimum there must lie a broad field in which it is necessary to determine each case on the basis of the peculiar conditions surrounding it, including the proximity and availability of equipment and the force suited to each class of work, and particularly the urgency of the work.

"The following figures are offered from experience, as pertinent to the question:

> Manual riveting is ordinarily most desirable where not more than 50 rivets have to be driven.
>
> In cases where it is impossible to establish any general rule, where each has to be decided on the basis of its own conditions, the number of rivets to be driven ranges from 50 to 100.
>
> Pneumatic equipment is usually most desirable for driving 100 rivets and more.

"While the foregoing figures are subject to modification as the conditions surrounding the individual cases may demand, they are believed to represent the outlines of this problem in as definite terms as it is possible to formulate."



From "Bridge Architecture" by Wilbur J. Watson

HISTORIC STRUCTURE DOOMED

Thomas Telford's famous suspension bridge across Menai Straits in North Wales was one of the first of its kind to be built. It has been an important link in the line of communication between London and Ireland since 1826, when it was essentially a stagecoach crossing. Today, because of structural weaknesses, it is open only to light traffic.

Menai Suspension Bridge Damaged by Gale

AFTER withstanding the onslaughts of a century of storms, the famous suspension bridge across picturesque Menai Straits separating the Island of Anglesey from Carnarvonshire in Wales, was seriously damaged by a gale on the night of January 9. Wind that reached a velocity of 100 miles an hour caused the bridge to swing clear of its moorings, and at one time there was a play of 18 inches.

Its main supports were also weakened; and when a yard-wide gap opened between the freely suspended section of the bridge and the span on the Bangor side of the straits, it was feared that parts of the structure would fall into the sea. Actually, a heavy iron member, on which the bridge swung laterally, became loose and eventually dropped into the sea. Only a few minutes previously an omnibus had passed over the structure. The driver of that vehicle afterwards remarked that he knew nothing of the damage, but had felt the bridge sway violently from side to side.

Now the bridge is held in place only by its iron chains and by the iron hangers by means of which the deck is suspended from the chains. Following an urgent message to officials of the Ministry of Transport, workmen labored all night to repair the damage, and the span was reopened to light traffic without much delay. The structure, which links the mainland with Anglesey, has for some time been known to be unsafe for the heavy traffic of today; and in all probability work on a proposed new bridge will be started soon.

Built by the celebrated engineer Thomas Telford—first president of the Institute of Civil Engineers—110 years ago, the Menai Bridge is one of the most graceful structures of its kind in the British Isles. The middle span is 580 feet from center to center of the main piers. Including the two end spans, which are supported by arches, the deck or roadway is 1,000 feet long and has a clearance of 100 feet above water at high spring tide. The deck is 30 feet wide and has two traffic lanes and a footwalk.

Begun in 1819, the bridge was constructed in about seven years—a notable achievement a century ago. Its cost was $600,000, also remarkable as compared with the cost of such structures at the present time. Telford took extreme pains to procure the best materials and workmanship throughout; and the stone, mortar, etc., are still in an excellent state of preservation, all things considered.

Chain carrying was begun in 1825, and was accomplished by floating out the center sections on pontoons and by hoisting them in place from that exposed position. The lifting was done by ropes, which were passed through large wooden pulley blocks provided with two or three sheaves and which were wound around capstans manned by a crew of 50. There was only one serious mishap, and that occurred during the early stages of the work when a pontoon was swept away by the current and part of the second chain fell into the straits and was damaged. There are sixteen chains in all, and the length of each between main piers is 590 feet and between anchorages 1,715 feet.

The bridge was opened to the public in January of 1826 by the Duke of Wellington. The first vehicle to cross it was the London-Holyhead mail coach. It was essentially a "stagecoach" crossing, and served as a vital link in the London-Holyhead Road the building of which was entrusted to Telford by the post office and other interests. The route is said to have been the means of opening up a new era in communication between England and Ireland.

The designer of the new Menai Bridge will find it no easy task to match or to surpass the old structure in which grace and stability were so well combined.

LESS FATIGUE—MORE WORK

WE ARE all familiar with the strip-cartoon advertisements that depict how much brighter Mrs. Brown looks at the end of washday since she learned to soak the dirt out of clothes with Bink's marvelous new powdered soap instead of rubbing it out as grandmother did. The laundry emerges from the ordeal seven or nine shades whiter, too, but the chief sales appeal is Mrs. Brown's beaming face as she greets her homecoming spouse in the evening and excitedly relates her amazing discovery.

This type of advertising may seem a bit ridiculous to men, particularly as nothing is told of how Brown feels. But there is really something to the idea back of it, according to students of such things, and they predict that Brown, too, is going to be perked up by making his work easier. Fatigue, they tell us, is a by-product of the expenditure of energy. Consequently, employers pay for fatigue if the work men do tires them to the point where their output lags. Hence the increasing attention to making tasks less arduous. This can be done by eliminating useless motion, by creating comfortable working conditions, by not pacing workmen and their machines too fast, and in many other ways. A large part of the Ford factory has been air conditioned primarily to lessen fatigue among workers and thus to improve their work.

If machines and tools are designed for easy operation, more of them will be sold because they will increase production. For example, a comparatively light rock drill of low vibration will accomplish more in a day in South African mines than a heavier, faster drilling machine. The reason is that a Kaffir "boy" has to hold the drill all day in a horizontal position. The heavier drill tires him quickly and his output suffers.

It has been determined that rhythm lessens fatigue in industry, just as it does when soldiers march in cadence, or when gangs of darkies work in unison to the accompaniment of a chant or song. Even if it is necessary to slow down a particular factory operation to secure rhythm, the day's production will be greater because the workman will maintain a steadier pace. Time-study engineers accordingly try to establish a rhythmical rate for each task.

TUNNELING—1936 STYLE

DRIVING tunnels once meant a dull cycle of drilling and hand mucking, and was about as imaginative as making mud pies. Today it is an art that permits the free exercise of engineering ingenuity. The transformation began with the first subaqueous bores. Time-honored methods would not work there, and special equipment had to be devised. Modern compressed-air tunneling is sufficiently thrilling to be featured in the newspapers and even in the movies.

Land tunneling continued to be a drab procedure for many years after underwater boring had been touched by romance. Then, about a dozen years ago, drill rigs began to come into general use. They permitted the massing of more men and drills at a heading and, in consequence, means had to be found of handling muck faster and also of performing the accompanying operations of placing supports and a concrete lining when the nature of the ground was such as to require them. From the first small drill rigs, such as the 4-drill units used in the Moffat Tunnel in Colorado, there evolved larger ones, the movement being climaxed by the 30-drill "jumbos" employed in the diversion bores at Boulder Dam. In their wake followed larger and larger mechanical mucking contrivances.

The jumbo idea spread, and similar built-up structures were provided for trimming operations and for the placing of concrete. Then belt conveyors entered the picture to speed up transportation. All these ultra-modern devices have been marshaled at Fort Peck Dam for driving the four diversion tunnels through unstable shale. In orderly procession they march through the hillside, each concentrating upon its allotted task. An authoritative article in this issue tells the fascinating story of their functioning.

ROCK-DRILL STEEL

THE cost of rock-drill steel represents such a small part of the total cost of most operations involving drilling that managements sometimes underestimate the true importance of dependable steel. There has been a tendency to consider steel just steel, any difference, in case it did exist, being hardly enough to matter much. We believe that this is faulty thinking.

Without having to refer to records, most mine managers can probably call to mind instances where steel breakage caused delays in production that considerably affected costs for that particular shift or day. Perhaps the steel was to blame, or maybe the heat treating was at fault. A careful study of the drill-steel situation might pay. Such an analysis should, by all means, be comprehensive. No true evaluation of the worth of drill steel can be made on first costs alone.

In an effort to make for a better understanding of drill steel and of the importance of using care in its selection, we present in this issue a general article that describes past and present manufacturing processes. Probably few users of such a prosaic product realize that it has occasioned so much research, or that its manufacturers go to such pains to provide steel that is just so, both inwardly and outwardly.

Tremendous improvements have been made in hollow drill steel during the past fifteen years. Strange as it may seem, the greatest advance has been of a mechanical nature: it has consisted of learning how to produce a smoother, cleaner hole. When steel-mill experts first began to emphasize the importance of these features in the case of the hole, even rock-drill manufacturers thought they were overdoing the matter, but time has proved that the character of the interior surfaces is in reality a vital factor that determines the life of hollow drill steel. For the method of rolling steel with an austenitic core, the industry has to thank Harry Brearley, a prominent British metallurgist who is best known as the inventor of stainless-cutlery steel.

This and That

School-House Changes

If persons past 40 were to revisit the schoolhouse of their youth, they would no doubt find that time has wrought many changes. Among the surprises to greet them might be a blackboard of glass instead of the familiar slate. We don't know just how far this replacement has gone, but we are informed that glass blackboards are now an established article of trade. When the first attempts were made to adapt glass to this service it was realized that the surface had to be roughened, and this was accomplished by sand-blasting. Panels so treated are satisfactory when new, but eventually wear shiny. To secure a permanently rough surface, one manufacturer has now introduced a board containing an abrasive that is uniformly distributed when the glass is in the molten state. Glass blackboards are claimed to be superior to those of slate because they are free from minor irregularities and because of their jet-black color which does not fade.

* * *

Rocket Aids Engineers

In order to span 1,500 feet of almost impassable South African mountain terrain with electric cables, recourse was had to the apparatus traditionally employed in getting a lifeline to a ship in trouble in rough seas. The first rocket landed within 60 feet of its objective, and the line that trailed it was then used to draw a wire across the intervening space. At another location, two attempts had to be made. Each rocket was designed to explode twice —once as it started its flight, and again in midair. The equipment was borrowed from marine authorities.

* * *

Salt to the Fore

The saying, "Not worth his salt", implies the small esteem in which salt has been held, despite the fact that it is indispensable to man and beast. Nevertheless, this common mineral has been put to numerous important uses in the industries and arts, and has recently assumed added significance in two diverse fields of service. Mixed with clay and gravel, it forms a road-surfacing compound that is virtually dustless, highly-resistant to heavy traffic, easily graded, and readily patched with more material of its kind. It compacts into a hard roadway that sheds water almost as well as asphalt. The mixture is ordinarily applied in a layer 2 inches thick, in which case two pounds of salt is sufficient to make enough material to cover a square yard. Many roads built within the past five or six years have been surfaced with it, and have come to be designated as Michigan roads because of their popularity in that state. At a recent meeting of the Canadian Institute of Mining and Metallurgy, however, it was divulged that the material was conceived by the owner of a Nova Scotia salt mine who wanted to enlarge the market for his product. This man was R. E. Chambers, who narrated the story of his nonsuccess with the Maritime Provinces when he first sought to introduce his development to them. Now the Ontario Highways Department has adopted the salt-clay-gravel mixture.

In its other new rôle salt plays second fiddle to the aristocratic new element deuterium, or heavy hydrogen, but its function is none the less important. Deuterium, a pound of which costs $13,000, can be teamed up with the lowly salt in the laboratory to produce a substitute for radium. When jets of deuterium gas impinge upon salt the latter becomes half as radioactive as pure radium, and its gamma rays are even more penetrating than those of any naturally occurring radioactive substance. Salt thus treated does not retain its activity more than a few weeks, hence it can be introduced into the blood stream of the human body without the danger that its effects will be so prolonged as to be harmful.

* * *

Coal-Mine Humor

Humorous remarks are frequently spontaneous. Oftentimes they are intended to be serious, and the person who makes them sees nothing in them to laugh about. Two examples of such inadvertant humor have been forwarded to us from England. In British coal mines, the deputies or undermanagers are required to file a daily report concerning underground conditions, and one of the questions refers to the compressed-air supply. Two reports recently handed in contained the following notations:

"Air bad; if it gets any worse, there will be none."

"Air very poor, and when it got better it was poor."

* * *

Citrus-Treated Steel

It is the boast of the meat-packing industry that it uses every part of the hog but the squeal. Now the citrus-fruit growers hope to use every part of oranges and lemons, including the peel. Having convinced a goodly proportion of the populace that the juices of these fruits are good for the temper of man, they now contend that their pulp is good for the temper of steel. W. E. Baier, research expert for the California Fruit Growers' Exchange, recently told the Farm Chemurgic Council, meeting at Fresno, Calif., that the pulp acts quicker than oil as a quenching agent and gives equal or better results. He stated that some steel companies are now experimenting with the new medium.

* * *

Costly Road Material

Near Wenatchee, Wash., county roadbuilders took a few tons of material from a mine dump for surfacing a highway. Several years ago they had drawn upon the same source under a verbal agreement with the owner to pay him five cents a cubic yard. This time, however, the owner claims that they hauled away good gold ore, worth $2,396, which was temporarily on the dump awaiting treatment. The county engineer contends that the old 5-cent rate should apply. The matter will be settled in the courts.

* * *

Believe It or Not

Despite the preachments of oil companies, the importance of using care in the selection and application of lubricants for machinery is sometimes lost sight of. Evidence of this is contained in the report of a serviceman from an American manufacturer's sales office in Spain. He was sent out to see why a small compressor, termed a beer pump, was not delivering air for pressuring beer. We quote from his written explanation: "I went to the bar where the pump was installed and found pieces of fish in the crankcase, which occurred as the result of using the oil out of sardine cans as a lubricant."

* * *

Fog Cures Concrete

A perpetual fog is maintained in the concrete-curing room of a materials and research laboratory operated by the California Department of Public Works at Sacramento. Compressed air at a pressure of 22 to 30 pounds is used to spray moisture into fans that blow across cooling coils. Thus the atmosphere of the room is kept at 70°F. and at 90 per cent humidity. In this room are stored test cylinders of concrete, which are mechanically broken after varying periods to determine their compressive strength. Temperature and moisture variations definitely affect their strength, and the uniform conditions are therefore created in conformity with the regulations of the American Society for Testing Materials. Test cylinders are usually broken in 7, 10, and 28 days after they are made, but for special studies they are sometimes kept in the room as long as ten years. The equipment that manufactures the weather is automatically regulated.

Industrial Notes

IN order to facilitate the work of making furnace repairs, of hot patching, of baffle construction and maintenance, and of applying protective coatings to new and old furnace walls, the Quigley Company, Inc., has built a refractory gun. The unit is portable, and handles premixed materials ranging from a light to a heavy consistency according to the needs of the job. These are shot in place with compressed air varying in pressure from 70 to 90 pounds for heavy mixes and from 20 to 50 pounds for light

mixes. The standard or P-A type has a capacity of 2 cubic feet, which is sufficient to cover 100 square feet of surface with a coat ¼ inch thick.

The gun is portable and is provided with a long hose connection and an extensible nozzle up to 20 feet in length, making any part of the walls or arches readily accessible either from the outside or the inside of the furnace. Because of the force with which the material is applied to either hot or cold surfaces, it is driven deep into cracks and crevices, filling them completely and assuring a firm bond. Two men are required, one at the gun and the other at the nozzle. While designed primarily for use in connection with refractories, the equipment can be employed for stuccoing, plastering, spraying, whitewashing, for applying rough coats of paint, and, by a rearrangement of the piping, also for sand-blasting.

A unique reference library where building materials are on file instead of books is being maintained in the Federal Warehouse in Washington, D. C. There it is possible for contractors and architects to examine marble, granite, limestone, etc., found in the various states of the Union as well as in Alaska and Puerto Rico. The displays are in two large rooms, one of which is given over to materials for exterior use and the other to those for interior purposes, and include samples of the various grades and finishes of each. Of marble, alone, there are as many as 192 polished or honed specimens. The primary object of this Government exhibit is to help architects planning Federal structures readily to select suitable building materials for them that are indigenous to the region in which they are to be erected.

DeVilbiss Company has developed a spray gun for acids and corrosive liquids generally. The unit is made of a molded plastic, and is designed for automatic operation. It differs from the standard type in that starting and stopping are controlled by the movement of a pneumatic piston that may be actuated at the gun or from a remote point by the use of a photoelectric cell or other suitable means.

It has been announced that the Third World Power Conference is to be held this year in Washington, D. C., from September 7 to 12 inclusive. The principal subject that will come up for discussion at this meeting is understood to be national power economy, embracing such matters as regional planning, fuel conservation, water power, and regulation of public utilities.

What is called a cave-in detector is being developed in the laboratories of Pennsylvania State College. The instrument operates on the same principle as the seismograph. A needle records the earth movements, which are transmitted through the medium of telescopic pipes attached to a spring and set up in the mine workings. It is said that the detector "should give at least 10-day notice of coming falls of mine walls."

Water-soluble glue spread over fine wire screening to which grout is to be applied directly under pressure will prevent wastage of material. This was tried not long ago in building a wind tunnel in the aerodynamics laboratory of the Georgia School of Technology. The framework of the tunnel was covered with 3x4-inch, 12-gauge galvanized wire mesh to which the screening was fastened. By going over this with glue the openings were reduced as much as 50 per cent, enabling the mesh to catch much more of the grout forcibly blown against it. After the inside surfaces had been lined the glue was washed off and the outer coat applied.

By what he calls a "vacuum-compression" method, Karl P. Billner, a Swedish engineer, claims to be able to reduce the curing period of concrete from 24 hours to twenty minutes. He recently demonstrated his process at Yale University by pouring an 8-inch slab which, according to the witnesses, was so dry at the expiration of the specified time that it could be jumped on without leaving an impression. The control slab took 24 hours to set and nearly a week to dry. Concrete treated by the Billner process, which makes use of atmospheric pressure and mats of rubber or metal, is said to be free from cracks and to be from 50 to 60 per cent stronger than that cured in the normal way. In addition, by putting grooves in the surfaces, it permits the making of nonskid pavements.

Ingersoll-Rand Company, 11 Broadway, New York, N. Y., is distributing an attractive bulletin fully describing and illustrating its channel valve for air compressors. Since this valve was introduced not long ago it has won increasing recognition because of the simplicity of its design, its durability, and its efficient and noiseless operation. It consists of a seat, of a stop plate, of several channel-shaped valves, and of a corresponding number of flat springs that are made to fit snugly in the

channels. According to the manufacturer, the valve channels lift straight off their seats without flexing and open the full length of the ports without impact. This is one of the valve's outstanding features. When the valve channels lift, a small quantity of compressed air is trapped between them and the springs, thus forming air cushions that float the valve channels to a stop. The channel valve comes in a wide range of sizes to meet most compressor needs.